UNIVERSITÀ DELLA CALABRIA

Dipartimento di Elettronica,
Informatica e Sistemistica

Dottorato di Ricerca in
Ingegneria dei Sistemi e Informatica
XXIII

Tesi di Dottorato

QoS Aware Multicast Routing and Meta-Heuristics over Multi-Layered Satellite-Hap Networks

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To My Love Darina

To My Princess Daniela

To My Hurricane Matteo

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Franco

Summary

In the last few years, multimedia broadband services and applications are growth. More resources have been requested to the networks and more Quality have to be supplied for the services. Moreover, new kind of networks were born such as wireless network and cellular networks such as 3G/4G and UMTS, also wired connections are evolved and more resources are available to allow new services and applications.

In these years, social networks and multimedia applications are increase exponentially making possible new field of applications. With new technologies, in fact, it is possible to supply utility services such as tele-health, wireless health monitoring, public safety services and much more services over the internet, WAN and so on.

Moreover, dedicated services and networks can be rapidly installed in case of emergency scenarios such as war or natural disaster cases.

For these reasons, new network architectures can be implemented to offer a wide range of services. In particular, it is thinkable to interoperate between different network such as Satellite network, Cellular network and Wired Network to take advantages from all networks reducing weakness. Moreover, it is necessary to increase resources availability making efficient choices and optimizing reservation along links on which network data flows.

To make these scenarios possible services and network have to offer a reasonable Quality in terms of Quality of Service (QoS). To do this new protocols and algorithms capable to take advantages from modern network infrastructures have to be designed. A wide range of services can be distributed on the network in a multicast manner, for example multimedia data such as video and audio can take advantages from multicast transmission reducing in a drastic manner the number of control packets and data packets sent into the network. In case of unicast transmission, in fact, a higher number of packets than the multicast are sent into the network to allow each destinations to receive data flows.

In order to make more robust, reliable and scalable multicasting on the hybrid network, a multicast algorithm has been associated to the the multicast protocol, when a multi-constraints QoS aware multicast have to be addressed. A multicast algorithm that has the main goal to find a multicast tree in an multi-constraints environment belongs to the NP-Complete class of problem. In literature this is known as a Steiner Tree Problem (STP). In order to solve this issue a new class of algorithms has to be addressed. In particular, taking into account limited resources of the routers and time limits a heuristic method has to be designed. In these last years a series of algorithms that derive by the observation of natural evolution and biological process that are also called biologic algorithms, pay out much attention. In this works, the Genetic Algorithm (GA) adapted to Multicast issues has been designed and proposed to provide a better resource management that allow a higher number of multicast sessions and higher number of users to join into the network. This allows a network cost reduction and offers better services with a higher quality to the community.

To spread services around wide areas with same quality, a broadband network, which are not sensible to terrestrial overloaded network, have to be addressed to distribute with reliability and scalability multicast services.

Satellite network equipped with newest architecture such as DVB-RCS or DVB-S2 that implements two way services represents an optimal solution to distribute broadband services, because it also support a certain realtime interaction between sources and destinations without changing of network. This architecture has the main problem to have a higher round trip delay owing to the distance between satellite and Earth surface, in fact, some applications such as realtime applications do not support satellite communications. For these reasons, and in general to reduce, where possible, round trip delay an intermediate network has been introduced into infrastructure. HAPs meshes are composed of several on air platform that provide wireless broadband communications. They can interact with cellular platforms or with most common wireless networks changing their payload if necessary. An interaction of Satellite and HAP can reduce delays and increase network performances. In order to make this possible an efficient multicast protocol capable to address in an efficient manner data flow and protocols interaction between several entities has been designed and proposed. Moreover, using aforementioned algorithm, efficient routing has been addressed. In this hybrid network, which is based on a DVB-RCS like architecture, local communication can be made exploiting HAPs or wired network. instead, in case of far connections satellite link can be used as bridge among HAPs network, otherwise satellite can be used directly to connect a terrestrial router with another one when HAPs links are overloaded or in case of some areas where HAP coverage is not present.

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Acronyms

ACM Adaptive Coding and Modulation
ACK Acknowledgment
BER Bit Error Rate
BG Broadcast Gain
BSMA Bounded Shortest Multicast Algorithm
CB Core Based
CBT Core Based Tree
CCDB-GA Constraints Cost Delay Bandwidth - Genetic Algorithm
COLM Constrained Online Multicast
CPU Control Processor Unit
DVB Digital Video Broadcasting
DVB-RCS Digital Video Broadcasting with Return Channel Satellite
DVB-H Digital Video Broadcasting for handheld terminal
DVB-S2 Digital Video Broadcasting - Satellite two
DiffServ Differentiated Services
DVMRP Distance Vector Multicast Routing Protocol
EMS End Multicast Session Message
FWL Forward Link
E-CBT Enhanced - Core Based Tree
EMS End Multicast Session
ETSI European Telecommunications Standards Institute
GA Genetic Algorithm
GEO Geostationary Satellite
HAP High Altitude Platform
HCDB-GA Hybrid Cost Delay Bandwidth - Genetic Algorithm
HEO High Earth Orbit
IGMP Internet Group Management Protocol
IntServ Integrated Services
ITU Internation Telecommunication Union
LDMS Local Multipoint Distribution Services
LEO Low Earth Orbit

LSA Link State Advertisement
MF-TDMA Multi Frequency - Time Division Multiple Access
MODCOD Modulation and Coding
MOGA Multi Objective Genetic Algorithm
MOSPF Multicast Open Short Path First
MPE Multi Protocol Encapsulation
MTDC Multicast Tree Density Coefficient
NCC Network Control Center
NCR Network Clock Reference
OBP On Board Processor
OSC Optimal Solution Coefficient
OSPF Open Short Path First
PIM-DM Protocol Independent Multicast - Dense Mode
PIM-SM Protocol Independent Multicast - Sparse Mode
QoS Quality of Service
RCST Return Channel Satellite Terminal
RIP Routing Internet Protocol
RP Rendezvous Point
RPM Reverse Path Multicast
RSVP Resource Reservation Protocol
RX Receiver
SA Simulated Annealing
SAMRA Simulated Annealing Multicast Routing Algorithm
SB Source Based
STP Steiner Tree Problem
TSA Tabu Search Approach
TX Transmission
UAV Unmanned Aerial Vehicle

Chapter 1
Satellite and Hap multimedia Network

In this chapter the reference network is described in details. As known, nowadays, more resources and more amount of contemporary connections are required in order to satisfy population services requirements. Moreover, the growth of service complexity and increasing of requested quality require a better resource management to be performed. In order to satisfy all requirements a multilayer architecture with a hierarchal organization has been addressed in this work[12]. This network is composed of a satellite layer based on Digital Video Broadcasting with Return Channel Satellite (DVB-RCS) standard that is connected with a High Altitude Platform (HAP) layer which could be organized into more HAPs mesh. This kind of network can floods several type of applications, moreover several fields of employment can be found.

This architecture is easy to configure and it offers robust communications and wide coverage areas. Furthermore, it can be used to solve last mile problem also in those areas where broadband communications are not available due to limitations of wired infrastructure. Multi Protocol Encapsulation (MPE), which is supplied with the DVB-RCS architecture, allow users to connect with the external TCP/IP networks offering a wide range of services and applications.

1.1 Satellite Network

DVB-RCS and current DVB-S2 satellite networks permit to send and receive data on uplink and downlink connection with high bandwidth. This permits several services to be distributed on this networks that previously were not allowed due to the architectural limits of the oldest satellite networks. Previously satellite networks allowed only one-way services to be addressed, because first generation of satellite was designed to only sent broadcast data that does not need an interactive modality. Satellite network is composed on a Satellite equipped with an On Board Processor (OBP), which communicates with several Return Channel Satellite Terminal (RCST). RCSTs allow end users to connect to the network, each RCSTs allow at max 16 terminals at the same time to be connected[25, 43, 42].

Satellite network, as known, offer high broadband wireless connections and wide footprint, but suffers by a higher round trip delay due to the distance between terminals and satellite. The DVB-RCS allow to interoperate with TCP/IP based network thanks to the Gateway (GTW) that supplies a redesigned TCP/IP protocol[18, 44, 45].

1.1.1 How satellite network works

The satellite network is composed of an OBP satellite node that communicates with several RCSTs in different areas. Each area is covered by a spot of the satellite that is also called spot footprint. The satellite network is also divided into two sections that are: space segment and the terrestrial segment as shown in Figure 1.1. The Space Segment is composed of the satellite and the Master and Control station, instead the Terrestrial Segment is composed of RCSTs nodes and gateway.

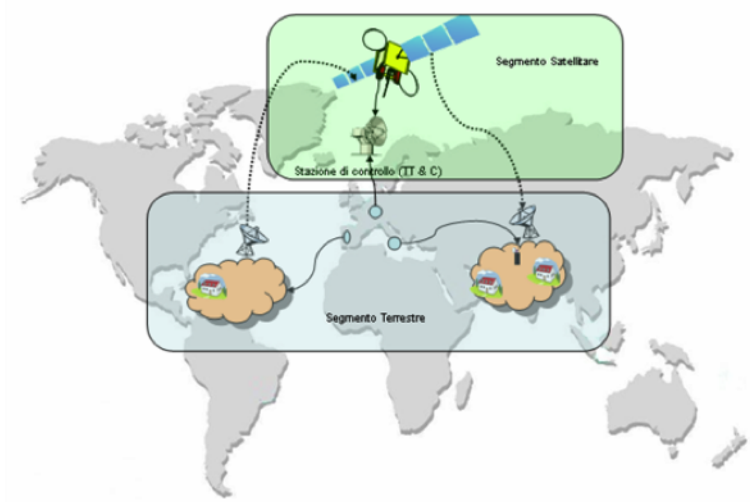

Fig. 1.1 Satellite Network Architecture

Satellite offers wide areas coverage and allows user to avoid territorial limit on quality of the communications, these limits are represented by national rules and laws. Moreover, robust and feasible communications are available, but several limits such as one-way communications, high complexity of terminals and the high cost of the devices make this architecture hard to spread and acquire wide slice of market [31, 32, 42].

1.1.2 Satellite Type

Several type of satellite networks exist, each type of satellite network offer different performances. Most common satellite type is the Geostationary satellite system where the satellite is located in an orbit around 36000Km far from the earth surface.

Orbit is the trajectory that a satellite describes during its travel around the earth. Satellite trajectory is designed to avoid that the satellite goes into gravity field falling to the earth. The trajectory minimize the force needed to balance the attraction force generated by the gravity. Orbits depends of satellite distance and inclination respect the earth equatorial plane or inclination respect earth axis. Most common orbits are:

- Elliptic Inclined Orbit : in this case the orbit is inclined respect the equatorial plane with an inclination angle of 64 degree. This orbit is stable and it is designed to balance the gravitational force, moreover it is well suitable for mobile communications because it solves problem related to natural or artificial obstacles. This orbit is used to supply services at high latitude such as earth poles.
- Circular inclination Orbit : Altitude of the satellite is constant, its inclination is around 90 degrees and it is particular suitable to cover all region of the earth.
- Circular Orbit with null inclination : This orbit presents an inclination angle of 0 degrees on the equatorial plane. Geostationary orbit is the most popular and known orbit. The satellite has an altitude that is constant. the satellite period time is the same of the earth, and for this reason the satellite seems to be a fixed point in the sky. This kind of orbit guarantees a coverage time of 24h per days and a greater footprint, in fact Three satellite are enough to cover all earth surface. This kind of satellite does not permits to cover polar area or high latitude.

Satellite systems like Geostationary Satellite (GEO) are easy to configure in terms of terrestrial and space segment and offer wide footprint, but they present a high round trip delay and the lower inclination angle does not permit to cover high latitude. Low Earth Orbit (LEO) systems offer lower round trip delay than GEO satellite and it is possible to use little terminals to receive signal. Therefore, handheld service can be supplied with this kind of satellite system, moreover the receiver chain is not complex and this permits a reduction of the terminal cost. LEO systems are lesser visible than the GEO and a constellation of satellite is needed to have a good footprint. Moreover, the satellite payload is more complex and a more complex protocols are needed to manage more frequent handovers. High Earth Orbit (HEO) satellite are much similar to a GEO satellite rather than the LEO satellite, therefore, we found high round trip delay and packet loss due to the altitude and environment condition, but taking into account their inclination angle these satellite make possible the coverage of high latitude.

1.1.3 DVB-RCS

The DVB-RCS standard is proposed by the European Telecommunications Standards Institute (ETSI) and its supply rules to be respected by the satellite architecture in order to distribute services and applications over the network. It is composed by a satellite, often equipped with OBP which has the capability to regenerate network flow cleaning it by the channel noise and increasing communications quality. Moreover, thanks to the MPE it is also possible to introduce into MPEG-2 Streaming TCP/IP packets[44]. This allows system to operate with multimedia Broadcasting services and internetworking services and applications.

DVB-RCS allows users to send packets in a two way manner, thus means that it is possible to send and receive contemporary using the satellite network. Moreover, high bandwidth is offer both in uplink and downlink segment. In fact in uplink the available bandwidth is up to 2 MBps while for the downlink it is possible to reach the 56 MBps[2].

End-user terminal transmits using a scheduled hub with a burst schema based on Multi Frequency - Time Division Multiple Access (MF-TDMA), this allows to achieve a slot temporal division of the transmission, but for each slot it is possible to send several services using several carriers. The forward link is the logical link that connects the HUB with the Terminals and merge video broadcasting with data flow of the TCP/IP layer. This link is based on the DVB standard that can use ATM or IP encapsulating this data into MPEG-2 TS. Forward link is used by the satellite only in order to transmit data in a broadcasting manner. Return channel is shared between the RCSTs that send data towards satellite and Gateway if data have to go outside the DVB-RCS network. Slots have assigned to the RCSTs taking into account user typology. In fact based on the user account the RCSTs can addressed a certain number of slots.

User Account	Available Bandwidth	Time Slots	Carrier
	144 Kbps	60	10
	384 Kbps	23	26
	1024 Kbps	9	28
Corporate	2 MBps	4	136

Table 1.1 User Account and Available Time Slots

1.1.3.1 DVB-RCS Architecture

The DVB-RCS standard provides to supply how DVB-RCS works. In particular, it supplies all information about each component of the system such as Satellite, RCSTs NCC, HUB and how signals have to be managed starting from coding, modulation signal power and so on. Moreover, log-in procedure, synchronization, TX and Rx parameters information are also given. System is composed of a Satellite that receives traffic from the RCSTs, Network Control Center (NCC) and HUB and distribute data among them. The NCC is an entity that manages sessions and supplies sinchro and transmission information to RCSTs. HUB has the main task to allow communication between DVB-RCS network and external network. Other details about network components are herein given.

The NCC has the main task to control and manage the network composed by satellite, RCSTs, feeder and gateway. The two way architecture has introduced several problem and the complexity of the system is increased, for these reasons the NCC uses more resources to make all tasks. NCC manages the network accesses and in particular the log-on procedures that each RCSTs have to perform in order to receive network services. In fact, to allow a RCSTs to log into the network the NCC has to send the Forward Link (FWL) information and the clock synchro (Network Clock Reference (NCR)). Once the NCR is set and the log-on procedures is successfully end, the NCC sends towards the RCST all information about the network and transmission configuration. The NCC has the possibility to disconnect a RCST and change transmission parameters if something change during the session.

The HUB is a key element of the DVB-RCS architecture, it supplies connection between terminals and external network allowing internet-working. In particular it supplies the following services

- Manage traffic coming from the internal terminals that uses the Return Channel of the satellite network;
- Manage accounting services to supply interactive services and connection with external public network;
- Allow connections with external server provider, DB and multimedia services also in pay per view;
- Allow connections from external traffic towards internal devices using MPE to exploit the DVB forward link to reach devices;

The RCSTs are used by the users to achieve access at the network, Using the RCSTs it's possible to receive services by the interactive network and communicate with other devices that belong to the network and other user that are external at the network but connected to internet. In case OBP satellite RCSTs can communicate among them directly saving time and increasing robustness of the system. The RCTs allow user to exploit the return channel of the network.

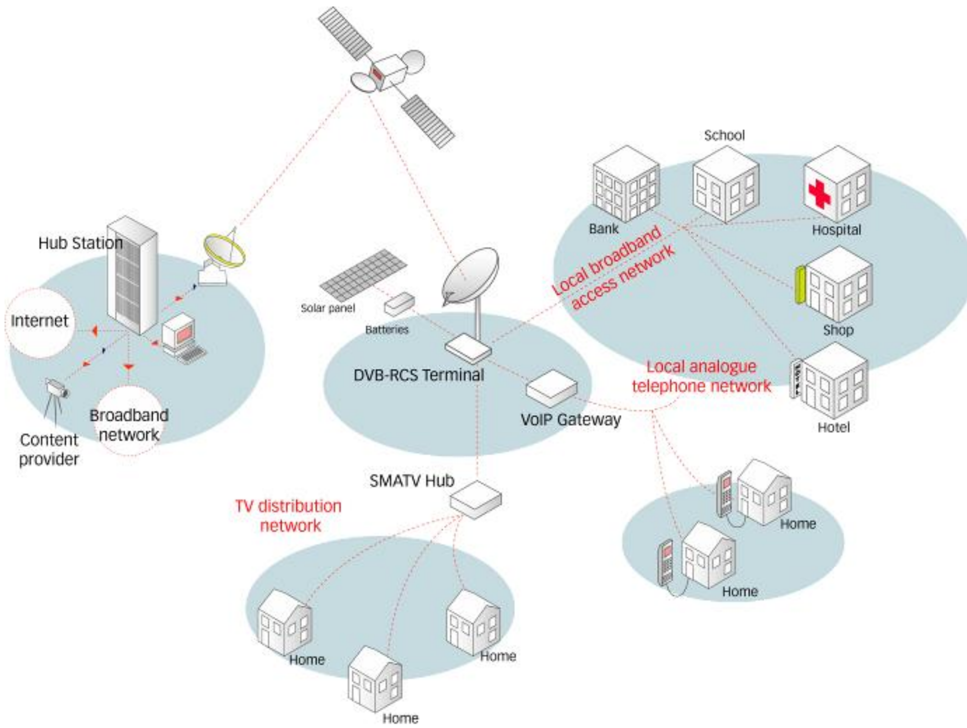

Fig. 1.2 DVB-RCS Architecture

In these last few years several updates have done to the DVB-RCS standard and in particular DVB-RCS+M and DVB-RCS2 standards have been presented. The DVB-RCS+M is even a DVB-RCS platform that supports Digital Video Broadcasting - Satellite two (DVB-S2) standard that allows us to achieve enormous advantages such as more robust transmission and reduction of packet loss, moreover a better QoS is supplied taking into account the capability of the new standard to better manage class of traffic thanks to new packet scheduling on satellite payload. Moreover, the capability of the RCSTs to change the Transmission (TX) parameters taking into account environments conditions guarantees that the transmission better adapt to external conditions such as climate and overload of the network.

On the other hand, the new generation of satellite networks (DVB-S2 standard) are based on interactive and adaptive bidirectional links, allowing a data rate up to 2Mbps for each user in return link, that provides better performance and robustness respect the previous standard. DVB-S2 was developed around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity. These goals are also obtained through the Adaptive Coding and Modulation (ACM) for the forward link: in fact, DVB-S2 can perform several kinds of Modulation and Coding (MODCOD) allowing to achieve a wide range of configurations and a very flexible system capable to adapt itself to the channel variations[54, 19, 14, 7]. Nowadays DVB-S2 is widely investigated owing to its capability to outperforms other similar technologies. DVB-S2 standard permits to distribute several types of services with a certain Quality of Service (QoS). ACM technique permits to adapt satellite FWL to Channel condition respecting the QoS requirements. A suitable resource management is a key factor because it can enhance the overall system performance exploiting the ACM technology. Moreover, ACM permits to give the possibility to adapt the system to the user preference and application requirements. Thus, it permits to obtain a more flexible system. Therefore, it is very important the communication from Satellite terrestrial Terminal to Satellite. In fact, Satellite Terminals send feedback messages towards Satellite, which contains information about the quality of the received signal.

1.2 HAPs mesh

HAP covers wide areas with a high bandwidth both in uplink and downlink, moreover an inter-hap communication is allowed. Using HAP it's possible to cover several areas such as urban, sub-urban, rural and disadvantaged areas. HAPs are easy to configure and new networks can be installed without terminal configurations, if terminals are just configured. This make possible to install new networks avoiding time wasting. Moreover, HAPs can be installed using light airplane, air static ballon or most recent UAV, where human pilots are not needed, this permits to save time and reduce risks for human life. Useful working time is increased and only maintenance and autonomy issues can force terminals landings. This terminals present a leak side related to their autonomy[30].

Each HAP can communicate with other one exploiting inter-hap link and high bandwidth is guaranteed. HAPs are organized into several groups where each group being to be a mesh. However, HAPs solve several issues and well fit those problems related to crisis scenarios such as post natural disaster or war environments. Several kind of applications can be distributed such as videoconference, tele health, resource sharing, private communications and multimedia services. Moreover, HAPs can be used to distribute cellular services such as 3G cellular and Digital Video Broadcasting for handheld terminal (DVB-H) networks allowing handheld communications to be addressed (see Figure1.1.3.1).

HAP system represents a valid support to other technologies that actually are supplied, in other words terrestrial and satellite infrastructures. HAP supplies connection for several kind of terminals, which can be fixed or mobile or handheld. A commonly supported bit rate per link is around 20 Mb/s, this bit rate can be reached with a limited antenna[34].

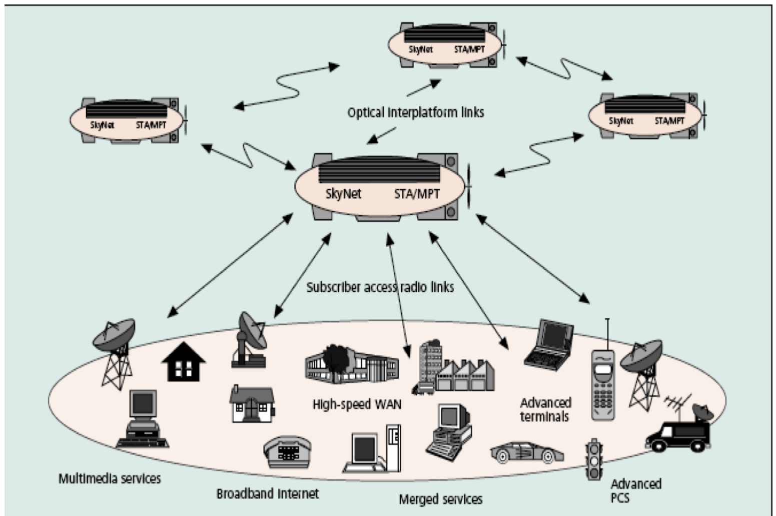

Fig. 1.3 HAPs mesh Architecture

HAPs allow users to communicate with high bandwidth and lower propagation delay. For these reasons this architecture has been chosen to interoperate with DVB-RCS networks. HAPs can be used to serve local area exploiting low propagation delay and high bandwidth. In order to communicate with far location the OBP satellite is also used. Moreover, taking advantage from the high bandwidth is also possible to offer the same class of services and applications of the satellite layer without loss of QoS.

HAPs are installed around 17-21 Km because in these atmospheric altitude no strong winds or turbulence are present. This choice is made due to stability issues of the HAP in order to allow stable connections and reduce unlike effects. Given an altitude and an elevation angle (γ) it is possible to find the coverage area using the following formula

$$d = 2R * \left(\arccos\left(\frac{R}{R+h} * \cos(\gamma) \right) - \gamma \right) \tag{1.1}$$

where R is earth range and h is the HAP altitude. For the elevation angle has been defined a lower bound that it's 5°. Each coverage area is subdivided in cells to increase coverage are exploiting the frequency reuse technique. In order to avoid area with too load the most useful elevation angle is chosen to be 15°.

Based on previously formula it is possible to identify coverage area having as key factor the elevation angle

Area Name and Description	Elevation Angle Range
Urban Area Coverage	[30°, 90°]
Sub Urban Area Coverage	[15°, 30°]
Rural Area Coverage	[5°, 15°]

Table 1.2 Coverage areas of the HAP based on elevation angle

1.2.1 HAPs types

the HAP are suitable to offer a wide range of services and applications, moreover due to the wide range of services that they can supply several payload types have been developed. For these reasons several kinds of HAPs have been designed. Most common vehicles are aerostatics ballon, UAV and airplane

1.2.1.1 Aerostatics Balloon

This type of HAP is essentially 150 mt. length. Their position in air is maintained using electrical engines that exploit solar panel to exploit solar energy. These panels are positioned at the external of the balloon.

Fig. 1.4 Aerostatics Balloon

1.2.1.2 Airplane

The airplane HAP are maintained in air for 8 hours, they are driven by a pilot and a copilot and a 24 hours a day service coverage is always guaranteed. Support airplane is sent in prefixed time slot to allow airplane turnover. Once they are active they make a circle to supply service at 22 Km of height.

1.2.1.3 UAV

This kind of vehicles represents a valid alternative to the previously systems. They are acquiring several market because they are pilot free and they land

Fig. 1.5 Airplane HAP

only for maintenance and refueling issues. Since they are ultra-light systems a little fuel tanks is present, for this reason they can be sent on air only for a limited time.

Fig. 1.6 UAV - HAP

1.2.2 HAPs Available Frequency

The range of used frequencies is wide due to the nature of the HAPs that allow several kind of communications. The dedicated bandwidth are 122 band of 300Mhz each one around 47-48 GHz. For the wireless access with Local Multipoint Distribution Services (LDMS) are commonly used microwave frequencies across the 26 GHz and 29 GHz bands. For the broadcast communications a bandwidth around 29.1-29.25 GHz is used while for the Mobile operator (3G network) it's possible to use the bandwidth around 900-1800 MHz for GSM and 1885 and 2200 MHz for the UMTS. Moreover, HAP can be also used to distribute applications using the WiMax standard and the used band are typically 2.3 GHz, 2.5 GHz and 3.5 GHz (see figure1.2.2).

HAP offers many advantages but also presents several issues. Propagation is limited by the diffraction due to the high frequencies, which are used by the HAPs. This represents a limit for communication and also in terms of QoS, in particular for those metrics related to the packet loss ratio. In the HAP networking some transmission issues are present and hard to be faced, these are herein described :

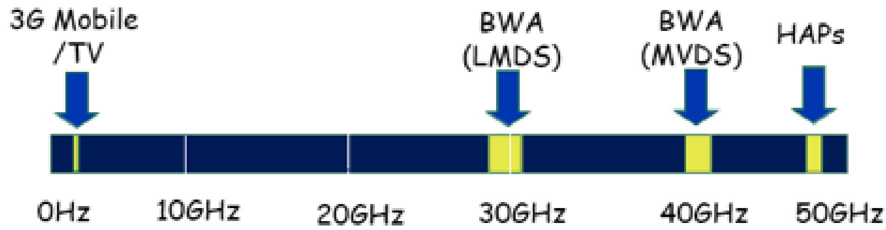

Fig. 1.7 HAP available Frequencies

Distance
: Far is the distance and high is the packet loss ratio, often the distance factor to being considered is quadratic D^2, in case of cellular transmission the factor is D^4.

Rain
: In case of rain some issues can be raise, in particular when a frequency around the 48 GHz and higher are used. In case of frequency up to 28 GHz rain effects could be not considered. The effects influence the power of the signals, in this way packet loss increase (see Figure 1.2.2).

Clouds
: In this case the power loss depends of the used frequency and increase with the increasing of the frequency. In the LMDS band the dB loss are 0.1, 0.5 and 0.9

Scattering
: Is the radiation loss due to water particle that the signal meet during the travel, in this case the radiation are spread along the cells that use the same frequencies.

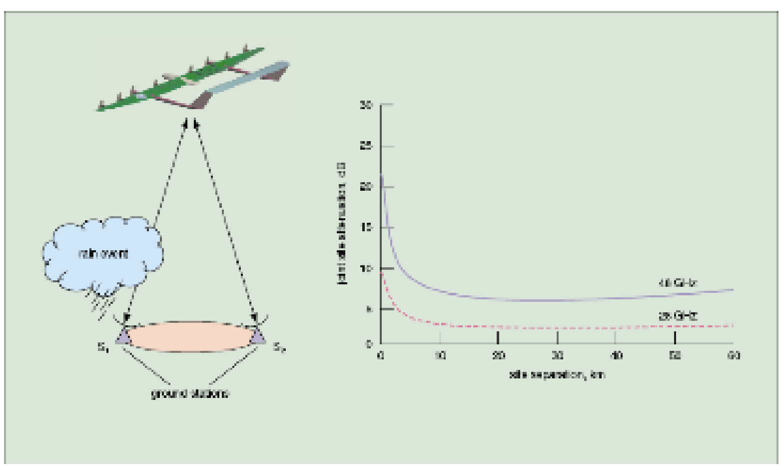

Fig. 1.8 Rain Effects on Signals

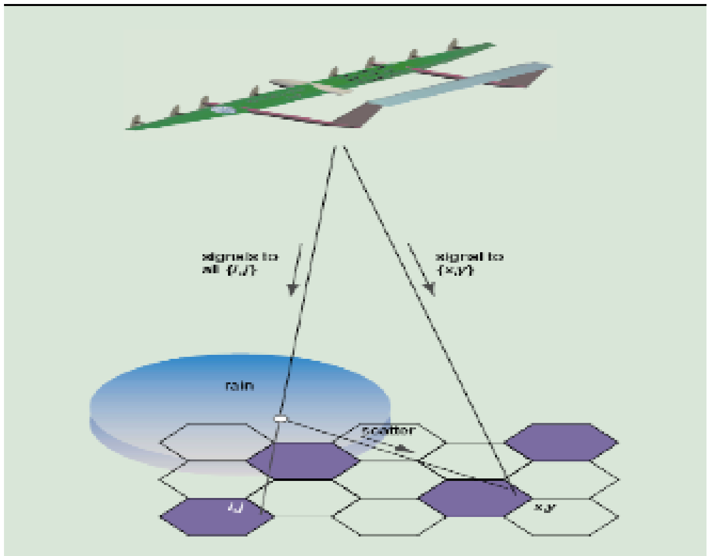

Fig. 1.9 Scattering Effect on Signals

One of the main issue of the HAP is the positioning of the platform and the maintaining of the stability. It is important that these two parameters have to be respected because in case of loss of stability the overall quality and performances of the system is wasted. The Internation Telecommunication Union (ITU) has designed that the platform has to be localized into a sphere of 500 mt. of radius. The maintaining of the position and stability represents a great issue for these vehicles, main problems are strictly related to stratospheric winds and turbulence. Winds and Turbulence might causes some problems that are more visible on light weight vehicles, instead greater vehicles are more stable and offer better performances. In order to solve this kind of problem it is possible to equip vehicles with antennas array that can change its position, antennas are designed to follow position and stability of the vehicle. Otherwise, it is possible to equip vehicle with mechanical hardware capable to correct position and stability. These solutions are possible but are very expansive in terms of cost.

1.2.3 HAP communications system advantages

In this section the possible advantages of the HAP communications are treated. HAP allows communication in a widely area due to their capability to cover wider area than a terrestrial system infrastructure. Moreover, terrestrial infrastructures need a greater amount of economic resources to be placed and a greater Natural impact than the HAP system.

HAPs offer a good flexibility to the traffic load due to their capacity to reuse frequencies and cells rearrangement. Moreover, HAP can be placed in different location in a easy way and with low cost. The HAP network is scalable respect the network size and load, in fact if more resources are needed other HAP can be connected to others exploiting inter - hap links, which offer a broadband connections allowing communications between HAP and HAP.

One of the key factor of the HAP system is that a complete system can be installed in a short time. In opposite condition, when the HAP system has to be installed also a short time is needed to perform this procedure, this allow us to save a lot of time and resources. Therefore, HAP can be rapidly used and they can be used in those scenarios where an emergency has to be treated shorter.

The mean time of life of a HAP is around 5 years, but sometimes a HAP can land due to payload updating or maintenance issues. Moreover, HAP is energy safe, solar energy is used to supply energy at whole system and they are impact free.

1.2.4 HAP communications system issues

The main issues of a HAP network are herein described, since the system was operative the ITU has assigned to the HAP high frequencies, which are around 47-48 GHz. At these frequencies the rain effects and the scattering effects are not treasurable but a more efficient transmission schema has to be used to supply services with a certain quality, in particular frequencies reuse has to be designed with more attention. To use network in a better way, a more efficient coding and modulation schemas have to be used in a broadband context. Moreover, QoS parameters such as the Bit Error Rate (BER) have to be considered.

Resources allocation and network protocols are under develop because a HAP system is different from other systems such as satellite, mobile or terrestrial architecture. It is interesting to develop protocols that can consider hybrid network composed of HAP, Satellite and terrestrial architectures at the same time. At the MAC level protocols have to take into account IEEE 802.16/ ETSI BRAN standard. As shown in section1.2.2 much important problem to face are the stability when a turbulence acts on the HAP, and the environments conditions such as snow, rain and so on.

1.3 Heterogeneous Network

The proposed architecture is a hybrid network with a Satellite layer, an HAP layer and the lower layer is composed of several end user terminals, which are connected with their local router known as RCSTs. The architecture is a DVB-RCS like platform that takes advantage of the large coverage area of the satellite system, and it can take advantage of the lower propagation delay of the HAPs layer. In fact, today more services are requested from the end user, some of these are sensitive to the bandwidth while others are sensitive to the end-to-end delay or to the jitter delay and so on.

Thus, the hybrid architecture can satisfy a wide class of services. Moreover, as is known the HAP is a mobile platform that is flexible and it can offer several wireless services; HAP can cover a city region and rural zones too. Some services can request one or more requirements (QoS constraints) to offer high quality to the end users.

In these last few years an increasing demand for broadband services and QoS guaranteed services has been requested by the users. In this field the multicast routing is increasingly utilized in order to supply for a differentiated type of services such as video conference, e-learning, e-entertainment, and multimedia contents and so on. Therefore, an integrated architecture composed of two layers could be used to distribute broadband services.

In particular, it is possible to distribute multimedia contents considering the hap-layer for a nearby region and to use the satellite as a bridge to reach distant regions. Moreover, it is possible to use the hap-layer to distribute real-time services into the network, and satellite links for those services that are not real-time sensible such as e-learning or video distribution [6]. Another interesting application field could be public health, civil protection, war field and post natural disaster field. In particular, HAP system is easily configurable and in order to start up the system a short time is needed. Thanks to the HAP layer local centers could intercommunicate in a shorter time; moreover, they could contact the coordinator center that could be in a far region or in another state exploiting the satellite link communication. The inter-hap mesh communications is made using satellite node as bridge.

In order to match with these requirements it is important to work with an algorithm and protocol that can satisfy the request of the services. Multicast paradigm offer a wide range of application fields, assuring that a better resource management and a reducing number of packets that flows on the network. Moreover, multicast allow us to use two kind of paradigm one is the many to many where many sources communicate with many receivers; the second paradigm that is the common is the one to many where a single source per multicast session sends packets towards many receivers.

Knowing the benefits and drawbacks of the network, which offers a large footprint but higher propagation delay for the satellite layer and low propagation delay, but a small footprint for the HAP layer then it is possible to build an algorithm that focuses its optimization parameters taking into account network capabilities. The algorithm must find best multicast tree with the greatest bandwidth and the shortest average end-to-end delay. As demonstrate in a further section of this works the algorithms that are capable to face with this scenarios are very complex and a classic approach cannot be used due to resource limit and complexity reasons. Then a heuristic and in particular a meta-heurists shall be proposed to address this problem.

In this work we have focus our attention on the GA meta-heuristic. This meta-heuristic was chosen because it is simple, efficient, robust, reliable and scalable, moreover it works with not complex data structure; however, found solutions are not so far from the optimal solution; owing to these reasons, it is unsuitable to use exhaustive search methods in a real context due to the limited computational resources of the router and due to the time limit. In this way the overall system performances can be enhanced and a more scalable and reliable system can be obtained.

In the multicast context is important to take into account multicast tree maintenance and rearrangement because multicast sessions present high dynamics such as join/leave procedures, nodes/links failure and so on. During join process new branches can connect an unknown subnetwork and new routes that are more efficient could be find. Taking into account the broadcast nature of this kind of network it is possible to exploit broadcast to reach multicast destination in a more efficient manner achieving a better resources management.

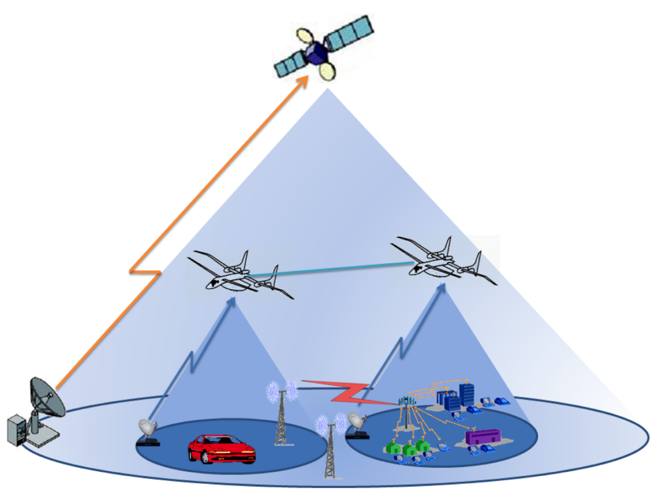

Fig. 1.10 Multilayer Architecture

As shown in Figure1.3 we are going to describe the reference architecture. The considered architecture is a hybrid multi-layer system composed of an On Board Process (OBP) Geostationary DVB-RCS Satellite which cooperates with a HAP mesh [30, 12, 13] . Both Satellite and HAP's mesh cover with their spot-beams a set of terminals called Return Channel Satellite Terminals (RCSTs), with reference to DVB-RCS terminology [31, 2] . The overall platform is a DVB-RCS like architecture where the HAPs have been introduced. HAP is equipped with a regenerating communication payload, which increases platform complexity, as well as weight and power consumption. In this scenario the multicast concept has been introduced [32, 18] in order to evaluate the performance of our proposed multicast algorithm.

The chosen architecture is a DVB-RCS like architecture where multicast services are supplied to the end-users. As aforementioned illustrated several scenarious can be addressed. In order to achieve maximum of the network a scalable and reliable multicast protocol that interacts with the GA multicast algorithm shall be designed.

In the following chapters the multicast protocol and algorithm shall be illustrated taking into account that the multi QoS constraints problem has to be addressed. Our challenge is to make a perfect interoperability between protocol and algorithm that face with a multi-constraints scenarios, this permits to achieve a better resource management allowing a higher number of users and multicast groups to join into the network. Moreover, a better quality shall be supplied increasing the overall quality of the offered services and a higher user satisfiability is obtained.

1.4 Conclusions on Chapter 1

In this chapter a description about reference network is given. First of all a brief description about satellite network has been done. Reference architecture is a satellite network based on DVB-RCS standard which is composed by an OBP satellite and several earth terminal capable to send and receive packets from the satellite architecture. This system permits to exploit high bandwidth services both in uplink and downlink. Moreover, thanks to the DVB-RCS and Multi Protocol Encapsulation protocol it is possible to easy interoperate with TCP/IP based networks. Satellite networks offer high coverage areas and robust connections. In order to enhance network performances and solve end-to-end delay a HAP meshes have been introduced. HAPs allow user to exploit high bandwidth service having low cost terminal. HAPs meshes are not worldwide available but where available permits to have easy configurable network and high configurability.

At the end the resultant network is composed of an OBP satellite that is connected with HAPs meshes and RCSTs. HAPs meshes and each single HAPs can communicate with other HAPs, Satellite and RCSTs while RCSTs can communicate with HAPs and Satellite too.

Hierarchical multilayer network is composed as herein shown:

1. First layer is composed by an OBP Satellite;

2. Second layer is composed by HAPs meshes;
3. Thirty and last layer is composed by the RCSTs;

Multilayer network can be used to solve last mile problem, allowing where possible use of low cost terminal to connect at the network. Moreover, several advantages are supplied such as:

- high footprint, in fact Urban, Sub-Urban and rural areas can be covered by the same network;
- easy network configurability, in fact this network and in particular HAPs can be easy moved from an area to another easiest, saving time and cost of installation;

Several scenarios such as natural disaster, civil protection and war scenarios can be easy supplied with the proposed infrastructure due to the large footprint of the satellite network and thanks to the faster reallocation or installation of the HAP system that can be drive on site where their presence is needed. Broadband networks allow several services to be addressed, for example in emergence scenarios high priority has to be assigned to life saving procedures. To do this tele-medicine, videoconferences, survive rescue services and resource sharing are only some examples of services that have to be available at first in order to rapidly organize local forces sending orders and knowledges from general headquarters to on field subsidiaries. A flexible and robust backbone permits to offer more services with an higher quality and allow operator to provide new solutions in different field of applications. In accordance with that, multi-constraints QoS Multicast aware can increase network performances providing better resources management. Today, a higher number of users have access to the network and a better management avoids to overload the wired terrestrial networks, which are overloaded for several reasons, herein some of the are reported:

- growth of the multimedia services requestes in terms of resourses and time management;
- increase of access due to the paradigm every where-every time;
- increase of the on-demand services and the spreading of the pay-per-view and internet tv;
- increase of the use of mobile devices;
- increase of the online gaming where a lot of users exploit network to meet known and unknown people to make a game over the network.

Chapter 2
Qos multicast aware on multilayer hierarchical network

In this chapter QoS aware multicast issues are addressed. In particular, multicast is herein illustrated in order to better understand algorithms proposal, which will be illustrated in the next chapter. First of all a brief description about literature proposal around QoS multicast is given. In this section several works have been briefly described in order to acquire a widely overview of the problem. When multicast protocols and algorithms are treated in terms of analytical representation a brief description about network representation is proposed. In fact, as further shown each network can be represented as a complete graph in which each router is a associated a tagged network node. To each node several terminals can be attached, this terminals are assumed to be end-users or sources of the multicast services. After that an analytical formulation of the multicast issues is given. This represents the starting point analyze problems that are treated in this work.

2.1 Multicast Routing Overview

The request of multicast services are increased in exponential manner in these last few years and in particular in the field of multimedia services. Multicast can reduce resources allocation and enhance network performance in terms of QoS. Key factor of the multicast is the capacity to reduce packets number that flows on the network. Only necessary packets are sent from the source, after that the network will provide to send necessary packets to other nodes until each destination is not reached. Multicast routes its packets following a multicast tree that is searched or built in order to reach each destinations.

In the multicast routing two entity works together with the main goal to distribute data among all nodes that belong to a multicast groups; these entities are the multicast protocol and the multicast algorithm, this last one can be completely disconnected from protocols, in this case the protocol has the task to trigger the algorithm when needed. Use integrated or independent algorithm depends of network data to be distributed or from application type, moreover, several approaches exist to implements multicast such as centralized or distributed, shared or not, static or dynamic and so on.

With rapidly growth of hardware technologies and the rapid evolution of internet several types of applications have been developed. Once of the most common factor between these new applications and hardware is their complexity and requested quality. Often applications and services require a guarantee quality to be supplied. This issue is commonly treated with the QoS, which is used when services require feasibility, quality, robust connection error free transmissions and so on, which cannot be supplied with best effort services.

When QoS has to be addressed, some essential techniques have to be designed. For example

- Definitions and specification of QoS constraints and bounds have to be taken into consideration during a multicast sessions
- Multicast protocol and algorithm that addressed QoS have to be designed
- Efficient Packet scheduling has to be designed in order to avoid buffer overload and to adopt a certain fairness between class of traffic,;
- Resource reservation protocols have to be implemented in order to allow QoS services to be distributed on the network with a guarantee quality and continuity of the service.
- QoS management and multicast tree maintenance have to be addressed, in particular when high dynamic network have to be considered.

Some architectures have just designed, some of these are the Integrated Services (IntServ) and the Differentiated Services (DiffServ)[6]. A coomonly known protocol is the Resource Reservation Protocol (RSVP), it has been designed to allow resource reservation in the unicast/multicast transmission[52].

QoS aware multicast routing tries to achieve a better multicast tree distribution respecting some QoS constraints, which are going to offer some determinate performances. Therefore, a better resource utilization and higher applications standard will be achieved.In the IntServ with RSVP a protocols unicast/multicast has the main goal to build a path/tree, moreover, in those cases where the QoS constraints are not respected. hence the protocol has to look for another path/tree dropping oldest path/tree.

Another possibility is to allow connections that present a degraded QoS level, in this case RSVP checks QoS thresholds and if these thresholds are satisfied then the found solution is declared admissible, it is used to distribute network data flow between sources and destinations. QoS distributions is a very hard issues due to different reasons. The first for example is the different nature of the QoS metrics that generally a modern applications wishes to be respected contemporary.

In the Teleconference, on demand video, VoIP and web services a different kind of QoS parameter has to be supplied from the network, moreover, several bounds may have to be respected in order to guarantee a certain QoS level. In this scenario, routing is an hard issues because this kind of problem are not treatable with polynomial routing algorithms. Moreover, in those networks where users and link's state evolve rapidly is very hard to face problem with algorithms and protocols that present lower complexity. In this case network topology changes due to nodes mobility and connection states, tree management increases it complexity because more protocol messages have to be managed to maintain routers and connection states updated. In those cases where a tree is degraded an alternative branches or an alternative tree have to be find to maintain a certain QoS.

2.1.1 Multicast Tree

The problem of multicast routing can be reduced to the problem of finding a tree into a graph (G), this tree is identified with the nomenclature of T.

T spans all vertices of the multicast group (M) on G. Multicast communications can be of two types, that are source based and group shared. Main difference between the two category is that:

in the source rooted, multicast tree is optimized taking into account the source-specific multicast communications, instead in the group shared multicast service is optimized taking into account whole multicast group. In the other words in case of delay optimization for the two category we can summary the following behavior [36]

- Source-rooted, the delay is optimized per each pair source - multicast member
- group shared, the delay is optimized per each couple of multicast member, therefore the average group shared delay is optimized

The multicast tree in order to offer a widely class of services that respect imposed bounds on QoS has to match the following requirements:

- Scalability : A good multicast tree is scalable in terms of network and group size. A reasonable amounts of time and resources have to be taken.
- Dynamic group support : The dynamic of multicast group has to be supported by the multicast and if necessary a tree rearrangement has to be performed to avoid multicast tree degradation due to member join/leave.
- Survivability : The multicast tree should survive to several link or node failures among the session life cycle.
- Fairness : It should provide a minimum QoS to each member of the multicast group. It tries to dived the multicast effort among the node that belong to the multicast path. In other words multicast tries to not overload an area respect another one.

2.1.2 The life cycle of a multicast group

Multicast allows dynamic behaviors in groups management, it permits dynamic member join/leave and dynamic sessions to be addressed. Multicast may have local or WAN access and memberships at the same time that are related to the same multicast groups. Moreover, mobility and wireless access make hard multicast treatment in order to supply constraints QoS services. Dynamic memberships allow us to have the following types of multicast (or host) groups:

- Dense groups have members on most of the links or subnets in the network;
- Sparse groups have members only on a small number of widely separated links;
- Open groups are those in which the sender/source need not be a member of the group;
- Closed groups allow only members to send to the group;
- Permanent groups are those groups that exist forever or for a longer duration than do transient groups;
- Static groups are those groups whose membership remains constant in time;
- Dynamic groups allow members to join/leave the group;

A network architecture that aims to provide complete support for QoS multicast has to take into consideration transparent multicast service, to do this specific requirements on the network implementation have to be considered. To demonstrate the different functionalities that such a network must provide, The sequence of phases/steps relevant to the multicast session are:

- Multicast group (session) creation;
- Multicast tree construction with resource reservation;
- Data transmission;
- Multicast session teardown;

2.1.2.1 Multicast Group(Session) Creation

In the Group/sessions creation phase the first step is to assign an unique address to the multicast group such that the data of one group does not gone in conflict or overlaps others. Groups Id and Addresses are given to a multicast tree until its session does not expires. Similar to groups, group addresses are classified as either static or dynamic, depending on whether they are assigned permanently to a given group or assigned to different groups at different instants of time.

Commonly groups and addresses are treated in this way, a static addresses is assigned to the permanent groups, whereas dynamic addresses are assigned to those transient groups.

2.1.2.2 Multicast Tree Construction with Resource Reservation

Once the group is created, the next phase in the multicast sessions is the construction of a multicast distribution tree, spanning the source(s) and all the destinations, this process belongs to the QoS routing issues, once a path is chosen then the resource reservation process is started and all needed resources are reseved along the paths. Multicast route, is often formulated as a problem related to tree construction. Herein the mainly reasons to use tree is reported:

- The source needs to only transmit a single packet down the multicast tree.
- The tree structure allows parallel transmission to the various receiver nodes.
- The tree structure minimizes data replication, since the packet is replicated by routers only at branch points in the tree.

It has been demonstrated that the process to find an optimal multicast tree for a static multicast group can be modeled as STP in networks, which is shown to be NP-complete. An additional dimension to the multicast routing problem is the need to construct trees that will satisfy the QoS requirements. QoS routing and resource reservation are two important, closely related issues. Resource reservation is necessary for the network to provide QoS guarantees. With QoS support, the data transmission of the connection will not be affected by the traffic dynamics of other connections that travel on common links. Before the reservation can be done, a tree that has the best chance of satisfying the resource requirements must be selected.

2.1.2.3 Data Transmission

Once the above two phases have been completed successfully, data transmission can begin. During the lifetime of the multicast session and after that the multicast group has been created then it is possible to identify the following dynamics:

Membership: Since group membership can be dynamic, the network must be able to track current membership during a session's lifetime. Tracking is needed both to start forwarding data to new group members and to stop the wasteful transmission of packets to members that have left the group, identified as Constrained Online Multicast (COLM) routing. Tracking of membership dynamics may be done in either a flooding, centralized, or distributed scheme [**?**].

Networking: During the lifetime of a multicast session, if any node or link supporting the multicast session fails, service will be disrupted. This requires mechanisms to detect node and link failures, and to reconfigure (restore) the multicast tree around the faulty links/nodes. Note that multicast routing protocols based on underlying unicast routing protocols are as survivable as the routing protocol. If the multicast routing protocol is independent of the unicast routing protocol, it must implement its own restoration mechanism [41].

Transmission problems: This could include events such as swamped receivers (needing flow control) or faulty packet transmissions (needing error control). The traffic control mechanism, working in conjunction with the schedulers at the receivers and routers, is responsible for performing the necessary control activities to overcome these transmission problems.

Competition among senders: In many-to-many multicasting, when multiple senders share the same multicast tree (resources) for data transmission, resource contention occurs among the senders. This will result in data loss due to buffer overflow, thus triggering transmission problems. This requires a session control mechanism that arbitrates transmission among senders .

2.1.2.4 Group Teardown

At some point in time, when the session's lifetime has elapsed, the source will initiate the session teardown procedures. This involves releasing the resources reserved for the session along all of the links of the multicast tree and purging all session-specific routing table entries. Finally, the multicast address is released and group teardown is complete.

2.2 QoS Aware Multicasting

In this section the state of art about QoS multicast will be treated. In particular, QoS algorithms and protocols are described. First the multicast algorithms are faced and their issues are illustrated. Then the network protocols that provide multicast routing are proposed, in the protocols field several methods are available, as shown, exist centralized or distributed approaches or both. Due to the complexity related to the problem that we are going to face a description about the STP is given, in fact the class of problem treated belongs to the STP family.

2.2.1 Multicast Algorithms and Issues

Various classes of algorithms with different development techniques have been proposed. Some of them were developed with heuristic techniques, because these problems have a higher computational complexity. Multicast problems, with a lower complexity, consider simple routing with only one Quality of Service (QoS) metric and for this reason they can be solved with algorithms such as Prim, Dijkstra or Kruskal[36, 26, 37, ?]. When a STP [58] is considered then an NP-Complete problem must be faced; in this case, in order to solve the multicast routing problem, alternative approaches could be used. These methods permit good solutions to be found, close to the optimum solution, which are called sub-optimal. Many studies have been made and good performances have been obtained from heuristic techniques. A new heuristic algorithm, called Bounded Shortest Multicast Algorithm (BSMA), is presented in [56] in order to build a minimum-cost multicast tree with delay constraints. Two variants of the cost function are considered: the first one minimizing the total link cost of the tree, and the second minimizing the most congested (maximal) link cost. Instead of applying the one-pass growing of the multicast tree used in previous works, Zhu et al. proposed an iterative optimization process to further minimize the tree cost that is monotonically achieved after a series of tree refinements. An algorithm, which has been taken as reference in the field of heuristics, is the algorithm proposed by Kompella et al. [57] , in which the Steiner tree problem is analyzed considering one QoS constraint. In particular, the constraint under study is a bounded end-to-end delay from the source to the destination and, moreover, it considers the minimization of the multicast tree cost. One of the first multicast routing GA was the Haghighat algorithm [27] . It is a QoS-based multicast routing algorithm based on the evolutionary principle which proposes to manage multiple QoS constraints in an efficient manner. Haghighat et al. proposed a connectivity matrix of edges encoding scheme for genotype representation. Moreover, they present some new implementation methods for mutation, crossover, pre-processing phase and random creation of initial population. Another algorithm is the Multi Objective Genetic Algorithm (MOGA) [15, 22, 28] . This algorithm is based on two different techniques. As is known, in order to gain some advantage, the GA must have a good fitness function. This permits a good possibility of mating the best chromosomes, so as to have better individuals in the next generation. To perform the assignment of the fitness values to all chromosomes MOGA uses a technique of optimization, well-known in the field of Operative Research to minimize the multi-objective function. This function is composed of some terms that regard the cost, the delay and the bandwidth of the multicast tree that is to be evaluated. All multicast trees, represented by chromosomes are evaluated by the fitness function that passes through various steps. A second class of problem resolution is represented by a specific branch of the Optimization Research, which is called the Tabu Search Approach (TSA) . TSA is another method to perform the multicast routing with a certain number of QoS metrics; for example in the case considered the TSA can find a multicast tree that has the minimum multicast tree cost as proprieties and also respect for the maximum end-to-end delay allowed by an unspecified application. Algorithms that implement this type of heuristic to find a good solution are fast, in terms of execution time, but they do not assure that the solution found is optimal. The TSA proposed in [21] uses PRIM algorithm in order to move into solution space, but as is well known, this algorithm can be used only for one metric optimization such as multicast tree cost, delay, bandwidth, buffer load and so on; TSA goes to modify the PRIM structure so it can implement the respect for another metric. In [24] the authors propose a SA algorithm where the multicast routing issues are considered. In particular, the algorithm attempts to construct a QoS-based multicast routing tree with the lowest cost of network resources in multimedia group communication. In the [11] algorithm considers two QoS parameters: end-to-end delay and error rate. In addition, the requirements of Control Processor Unit (CPU) utilization ratio, buffer and bandwidth are also considered. In the authors propose a novel algorithm based on simulated annealing meta-heuristics, which is capable of tackling the delay- and delay variation-bounded Steiner tree problem that is known to be an NP-Complete problem[58]. Moreover, the authors also consider the cost minimization of the multicast tree. Their algorithm is called Simulated Annealing Multicast Routing Algorithm (SAMRA). SAMRA uses 'paths switching' strategy, which constructs neighbors in the range of feasible solutions according to the relationship between delay and delay variation. Moreover, SAMRA was compared with other multicast routing algorithms and the algorithm has demonstrated to have characteristics such as feasibility, stability and rapid convergence. It can effectively construct multicast tree with lower cost according to a QoS request, and has better real-time property. In [4] the CCDB-GA was proposed and better performances than another GA called MOGA were obtained in terms of execution time and solution optimality. In this paper several enhancements on the CCDB-GA, which take into account broadcast nature of the multilayer network, have been added. In particular, a new cost function was considered and the overall connection cost was amortized over those terminals that want to participate at some multicast sessions. Furthermore, the proposed GA was compared with another interesting meta-heuristic technique called SA. The integration of multicast routing and protocol have been also focused.

2.2.2 STP

In this section a brief description about the STP is given. The STPs are some problems that have a well known complexity. This class of problem belongs to the NP-Complete class and they are not easy to be solved. In particular is not possible to use polynomial algorithm to solve problem.

Unfortunately, in this work the class of problems that we are going to treat belong to the STP family. Since a multi-constraints QoS problem is faced an STP is meet.

The STP is a combinatorial optimization problem that is similar to minimum spanning tree problem. In the Steiner tree it is possible to add other vertices to the graph in order to find a tree that reduce the total length of the connections. Steiner Tree can be applied to several field also on the network problem. Steiner Tree are NP-Complete problem and only in some restricted cases a polynomial algorithm can be used to solve that problems. Further these cases shall be illustrated in our context. Considering the multi-constraints QoS multicast is easy to understand that we are going to face with a NP-Complete problem[58], which cannot be solved with a polynomial algorithm. Therefore, heuristics have to be used to approach the problem.

2.2.2.1 STP reduction

Although STP is NP-Complete, there are some trivial cases of STP that can be solved in polynomial time. In order to better explain reduction cases it is important to give some definition. With M terms all nodes that belong to the multicast session are indicated, With the V terms instead all nodes that compose the Graph G are indicated. Therefore, reduction cases are herein reported [36]:

$|M| = 2$: this is a unicast case where only two node are involved into communications, in other words, only a source and only a multicast destination belong to the multicast group

$|M| = |V|$: this is the broadcast case where all nodes of the network belong to the multicast group. In this case the SPT can be reduced to the well known minimum spanning tree problem. Polynomial time algorithms can be used to solve this sub-case of SPT(10,11).

$G(V, E) = T(V_T, E_T)$: G is a tree, network is just a tree, in this case only a sub tree exist to cover Multicast group (M). The found sub-tree is the solution of the STP. Also in this case polynomial time algorithms can be used.

Moreover, for certain cases the STP can be reduced applying the following rules (1). deg(v) denotes the degree of the node v.

1. If G contains a node v con deg(v) = 1 then v and the edge e(u,v) can be removed from G. In case of $v \in M$ and $u \notin M$ then u is added to M in the reduced Graph. Note that is $v \in M$ also the link e(u,v) belongs to the Steiner Tree.
2. if G contains a node $v \notin M$ with deg(v) = 2 then two links e(i,v) and e(v,j) can be replaced with a new one link e'(i,j). where $c_{i,j} = c_{i,v} + c_{v,j}$. If two parallel link have been present in the reduced STP then the one with higher cost is removed from the Steiner Tree.
3. if G contains a ling e(i,j) such that $c_{i,j} > d_{i,j}$ where $d_{i,j}$ is the cost of the shortest path between node i and node j, then the link e(i,j) is removed from G'. in case of $c_{i,j} = d_{i,j}$ and a path between node i and node j exist and this last path does not use link e(i,j) then the link e(i,j) could be removed from G'.
4. If G contains Three nodes $u, v, w \in M$ such that u and v are adjacent, moreover, the $c_{u,v} > d_{w,u}$ and $c_{u,v} > d_{w,v}$ then the link e(u,v) can be

removed from G'. In other words, if u,v and w are three nodes that belong to the multicast group M such that the cost of the link e(u,v) is more than the cost of a path from node w to node u as well as node v, then link e(u,v) does not belongs to the G'.

5. Let $u \in M$, let v and w be the closest and the second closest nodes adjacent to node u, respectively. if $c_{u,v} + min\{d_{v,p} : p \in M, p \neq u\} \leq c_{u,w}$ then the link e(u,v) has to belong to the G'. In other words, if exist and adjacent node that does not belong to M but has the capability to reduce distance between node u and other node that belong to M, then the link e(u,v) can belong to the Steiner Tree.

Unfortunately, often the STP applied to telecommunication network cannot be reduced using one of the above rules, and this is demonstrated by the lemma that we are going to show. Usually a reduction cannot be applied when $|M| \lll |V|$, The network is not sparse and G satisfies the triangle inequality.

Lemma if an instance of STP satisfies all of the following three conditions then STP cannot be reduced to a smaller instance of STP using one or more of the aforementioned rules.

- G(V,E) satisfies the triangle inequality that is the cost $c_{u,v}$ of a link e(u,v) is strictly less than the cost of any path from node u to node v which does not include link e(u,v);
- The minimum degree of G(V,E) is 3, that is $\forall v \in V, deg(v) \geq 3$
- Does not exist a pair of nodes that are adjacent and belong to the M set at the same time, in other words, $\forall u, v \in M \Rightarrow e(u, v) \notin E$

Thus implies that in a typical communication network it may be impossible to find a ST into a reasonable amount of time. Hence it is necessary to adapt specified algorithms such as heuristics. These kinds of algorithms give us the possibility to find a feasible solution in polynomial time, which is not of course the optimal one. This allows us to save time and resources of the routers that are evolved into multicast tree computation. Moreover, cpu cycles that are saved can be used from the router to make decision and manages QoS multicast sessions. This make more efficient QoS sessions and bring up more quality.

2.3 Multicast Protocols

After that the multicast algorithms have been described, most common multicast protocols will be described into this section. Commonly, multicast protocols are divided into two main category, first one is the SB protocols, where multicast routing and management is based on source of the multicast group. Second category is called CB multicast protocols where a node, that could be also external to the multicast group, is chosen to manage and finding routes to address packets, this router or node is called core or Rendezvous Point (RP).

2.3.1 SB Multicast Tree Protocols

Multicast tree is built taking as root the multicast group source, this has the main goal to connect each member of the multicast group. Packets, which are generated by the source, are distributed towards multicast destinations exploiting multicast tree branches. In this section are described the most common protocols that belong to this category.

2.3.1.1 DVMRP

This protocol builts its multicast tree exploiting the Reverse Path Multicast (RPM) algorithm. In this algorithm, when a datagram is coming from a source called (s), the router sends towards the output interfaces the datagram, this is made only if the datagrams coming from an input interface that belongs to the shortest path that connect source with the router. In the DVMRP sending of datagrams is made using the RPM paradigm, hence in order to have a multicast tree updated in a periodic manner datagrams are sent on all networks. A leaf node sends back a prune message if no members of the multicast tree are connected to its output interfaces, in this case each router that belongs to the multicast session update its forwarding table, avoiding to sent forward messages not used from other nodes. The DVMRP works in independent manner from the unicast routing and it uses the poison reverse update mechanism. Poison reverse mechanism has the main goal to avoid infinite loop in order in an efficient way the leaf nodes.

2.3.1.2 MOSPF

In the Open Short Path First (OSPF) each routers keep state and network topology informations updated using the Link State Advertisement (LSA). A router MOSPF can use this characteristic in order to build a multicast tree composed of shortest paths between sources and multicast destinations. Shortest path are built using the Dijkstra algorithm, instead the tree maintenance is made using the Internet Group Management Protocol (IGMP). The forwarding tables is not updated following a periodic update mechanism but they are updated each time that network topology changes or when multicast group changes.

2.3.1.3 PIM-DM

PIM can use dense or sparse mode. Dense Mode is related to a network topology where all group members are concentrated in a specific area of the network, therefore all available bandwidth is used by the nodes that are present in this area. The sparse mode is used where multicast groups are spread all around the network and the available bandwidth is not totally used. The PIM-DM is like DVMRP and uses the RPM, in the PIM-DM the unicast routing is used to exchange information among routers of the network, even more the network updating process is made in unicast manner.

2.3.2 CB Multicast Tree protocols

In this kind of multicast a router per group or a single router for all groups is chosen to be the core router, this node is also called RP. Multicast tree is build and use as root the RP. This node has the main goal to manage and distribute the multicast packets into the network.

2.3.2.1 PIM-SM

In this protocol only a RP is active per multicast group. An host that would to join in a multicast group, locally sent trough using IGMP a message to its parent router. Parent router build its forwarding table per each multicast group that it has to serve. It sends also a PIM join message in a unicast manner in order to reach the RP of the multicast group where the destination wishes to connect. Intermediate router that are used to travel the PIM-join message add the entry (*,group) in their forwarding table.

When a source host sends for the first time a packets towards the RP, this packet is encapsulated into a message that is called PIM-register, this message is sent towards RP in a unicast manner. Once this packet reaches the RP it analyze packet and send backs the PIM-join message. After that the join phase is made, source sends in multicast manner packets towards the RP. When multicast group reaches a certain stability message of PIM-join/prune are sent on all interfaces, this process allows to acquire network topology. In the PIM-SM mode is possible to change from a group shared tree to a source based tree, this choice is made taking into account source packets ratio.

2.3.2.2 CBT

This protocol is widely used and it is based on a Core router. This protocol has been chosen as base protocol for this work and it will be explained in details further. Here a comparison in terms of Network management is made between CB and SB protocols. The CB protocols offer a higher scalability when the number of sources increase. Moreover, those routers that not belong to a certain multicast sessions do not interact in the maintenance processes. In the SB protocols when management processes have to be performed a lot of messages are sent in broadcast manner on the network, and this is not positive in terms of scalability. In the CB this not happen because all information about network state are persistent into the RP or core router. The CB protocols, present the leak that the multicast tree could not be optimum for some sources. Moreover, in the CBT protocols an overload on certain branches of the multicast tree is present, this is not good because other branches or links of the network are not used. This could increase packets drop rate and delay wasting quality of the received services[**?**, 16, 48].

2.3.3 More on Multicast tree protocols

As aforementioned said the algorithm is used to find a multicast tree that satisfies some requirements and constraints, to have informations, which match with the current state of the network and to know network topology and state, a protocol is needed. Moreover, a good multicast tree help us to achieve a protocol much more scalable and robust and avoid to have an overload of the multicast tree branches.

2.3.3.1 Network State - Storing and Updating processes

Each node that belong to the network needs to know information about whole network or about its neighbors(partial knowledge). The type of information can be kept in several forms: Exact, Probabilistic[50, 51] or aggregate[55, 53].

To exchange messages between neighbor several protocols could be adopted such as Routing Internet Protocol (RIP) o OSPF, taking into account the chosen protocols nodes exchange informations with their neighbors.

Multicast protocols could use unicast protocols, which runs in background to storing information about network status. For example PIM uses unicast to keep updated forwarding table, instead DVMRP keeps its routing information exchanging protocol messages. Due to synchronization and delay issues related to these messages the network status often does not match with the real status of the networks and nodes.

2.3.3.2 Tree Finding processes

Protocols overload network with status messages exchanging with messages that are used to build multicast tree to manage it and keep updated its status. The main issue is to choose when tree computation has to be made. In this case it is possible to have two modality :

- On demand routing
- Precomputed routing

In case of on demand routing, routing computation is performed when a connection request is coming to the node, instead in case of precomputed routing routing computation does not depend of connection request. Sometimes it is possible to have some alternatives.

Some of the possible alternative are that, the routing computation is performed randomly or it is performed following some strict rules of triggering.

2.3.3.3 Tree management and assessment due to join/leave updating

In a multicast session often a certain group dynamic can be found, in fact the join/leave messages are very usually. Each host can join or leave from a multicast group in each moment of the multicast group life. In order to achieve an efficient multicast tree it is necessary that procedures do not waste the overall quality of the multicast tree, in other words the member join/leave does not influences the multicast sessions.

Supposing that the multicast tree is going to be rebuilt every time that a member leave/join is performed, the on tree nodes cannot change immediately their status and a transitions state has to be considered. When a host wants to enter into a multicast group a new branch that connect local router to the multicast tree has to be included into the multicast tree. If this procedure is performed, the multicast tree quality is going to be wasted every time a join is performed because the QoS is not optimized. When a host wants to get out of multicast session the branch that connect the local router of the host to the multicast tree is dropped. The multicast tree also in this case is degraded.

Several approaches are under develop to avoid this issue and one of this is to create a tree degradation index that will be monitored during multicast session time life. If this index is lower than a prefixed threshold then the multicast tree has to be rebuild.

2.3.3.4 Tree state management

Multicast protocols, in order to be robust the the message loss have adopted the soft state approach. It is easy and consist that each router keep its state for a prefixed amount of time, an example is supplied by the DVMRP that periodically deletes its state making a mechanism that allows datagram to be flood out by all interfaces. In many routing protocols that belong to the CB family(PIM-SM, CBT, SM), the soft state is periodically updated with some specific messages that are sent on the network. The state of the router is pruned if the respond message to a refresh message is not received into a specified time-out.

Main difference between PIM-SM and CBT/SM protocols is that in these last protocols, refresh messages are sent to keep state updated. Moreover, the on tree router state is not lost if the unicast protocols that run in background reports a load changing. This means that the multicast tree does not change as happen into the case of PIM-SM where a load change implies a tree reconstruction because some on tree nodes lost their state and in order to reach all destinations a new path has to be found.

In order to avoid this problem, in the CBT some particular messages have been introduced such as CBT echo request/replay messages, these messages are sent between neighbor routers in an unicast way[46, 48].

As further shown these messages are used to avoid CBT problem and they are used to supply state updating and QoS management. This is made to achieve a more efficient packets flooding and a better services quality.

2.3.3.5 Scalability

With the growth of the networks and their interconnections, the size of the forwarding tables increases exponentially, also the traffic and the overhead of protocol increase. This make hard to manage information storing and message forwarding for the routers that compose the network that generally are equipped with limited hardware resources. For these reasons it is important to consider the scalability of the protocol as a key factor in the protocol developing phase. If this is not made, router cannot manage all these informations and they cannot perform some based operations due to resources wasting.

2.4 Problem formulation

The QoS multicast is a problem that has an enormous relevance in the world of telecommunications for various reasons. One of the most important reasons is the low data flow in the network. When a multicast session has been started only a single copy of a determined message starts from the source and flows through the multicast tree, so it can reach the entire group of the multicast destinations. The problem is to find a good tree that can respect the imposed bound over delay and bandwidth and, moreover, that minimizes the total cost of the tree. This problem is known as an NP-Complete problem and to solve it in a reasonable time a meta-heuristic method, which allows finding an acceptable solution (sub-optimal) in a shortest time, has been adopted. The multi-constrained QoS multicast is a frontier of research, because some applications can require a combination of metrics in order to reach the end-user desired quality; in the rest of this section the network model will be shown.

2.4.1 Network Representation

Each network can be represented as a not oriented and weight Graph $G(V, E)$ where V are the node set and E is the edge set. Link's weight represents the QoS metrics to be respected and minimized. It's important to take into account that each metric has a different nature and it is independent from the others. Each link of the Graph G has three different weights, which are associated with the considered QoS metrics. A generic link that connects a generic node i with a generic node j, is indicated as $e(i, j)$ and it has a structure associated with it that contains information about the considered QoS metrics such as link cost, link delay and link capacity. The purpose of the multicast, with QoS support approach, is to find a multicast tree that performs the QoS requirements and reaches each multicast destination. The multicast source router is the root of the tree, while the routers, which locally connect the multicast destinations, are the multicast tree leaf. Figure2.1 shows the example of a complete graph, while a possible routing tree is depicted in Figure 2.2 and it can be a possible solution. In this case the source is node 1, while the destinations are nodes 5, 6 and 7.

2.4.2 QoS Multicast Analytical Formulation

Each link that connects two nodes (u and v) is a two way link, this means that if exist $e = (u, v) \in E$ exits then exist $e^{'} = (v, u) \in E$. To each link a set of QoS parameters are associated, in particular a delay terms $\delta_{i,j}$, a bandwidth $b_{i,j}$, and cost term $c_{i,j}$. Taking into account multicast context it is possible to identify two subset of nodes for each multicast session.

Source Subset is filled with all those nodes that represents a source of traffic for the multicast groups, the subset is called Src and the eq.2.1 has to be verified

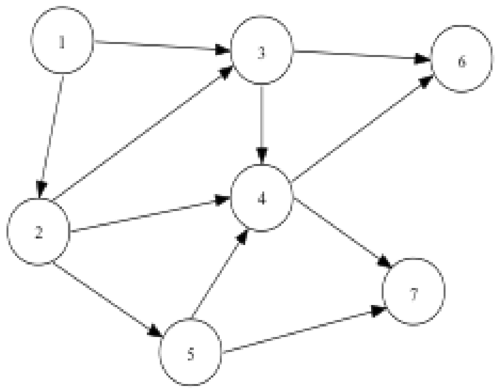

Fig. 2.1 Network Topology views as a Graph

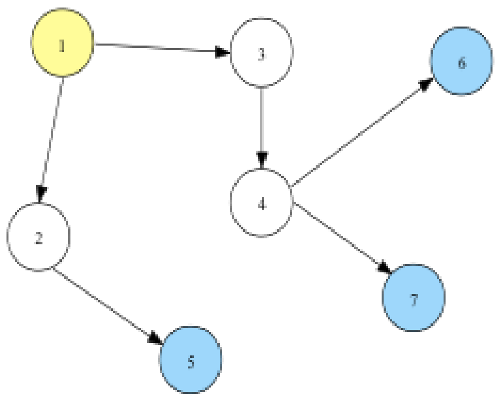

Fig. 2.2 Multicast Tree achieved from Network Topology

$$Src \subset V \tag{2.1}$$

Multicast Destinations subset is filled with all those nodes that join to the network to receive multicast traffic of a particular multicast session, its subset is called D and the has to be verified

$$D \subset V \tag{2.2}$$

A multicast tree is instead a particular sub-graph where nodes are reachable by only one node and root has no entry node, moreover, end nodes have the characteristics to haven't exit node. This subgraph will be indicated as herein depicted

$$\begin{cases} T(V_T, E_T) \subseteq G(V, E) \\ V_T \subseteq V \\ E_T \subseteq E \end{cases} \tag{2.3}$$

In order to reach a destination multicast data flows along a path, which is found by the multicast algorithm, it can be formulated as follow

$$P_T(s,d) = \cup_{i=s,j=s+1}^{j=v,i=v-1} e_{i,j} : e_{i,j} \in E_T, s \in Src, d \in D \tag{2.4}$$

Considering that the end-to-end delay is an additive metrics, it is given by the eq.2.5and it is the sum of each link delay among the source and the destination path.

$$\triangle(s,d) = \sum_{(i,j)\in P_T(s,d)} \delta_{i,j} \; s \in Src, d \in D \tag{2.5}$$

The available bandwidth is the minimum bandwidth found along the path between source and destination and it is given by the eq.2.6.

$$B(s,d) = Min_{i,j\in P_T(s,d)} \left(b_{i,j}\right) \tag{2.6}$$

The cost between a source and a destination is given by the eq.2.7

$$C(s,d) = \sum_{i,j\in P_T(s,d)} c_{i,j} \tag{2.7}$$

The overall multicast cost is given by eq.2.8 the and it has to be minimized by the multicast algorithm

$$Cost(T(V_T, E_T)) = \sum_{d\in D} C(s,d) \;, \; s \in Src \tag{2.8}$$

The overall minimum bandwidth is given by the eq. 2.9

$$B(T(V_T, E_T)) = Min(\forall_{s\in S, d\in D} B(s,d)) \tag{2.9}$$

The overall end-to-end delay is given by the maximum end-to-end delay among each couples (s, d), it is given by the eq.2.10

$$\triangle(T(V_T, E_T)) = Max(\forall_{s\in S, d\in D} \triangle(s,d)) \tag{2.10}$$

2.4.3 QoS Multicast Constraints

The main goal is to found solutions that satisfy several QoS constraints. In a multicast scenario modern services as multimedia communication, peer-to-peer, video and audio streaming, on line gaming, request for a ceratint level of QoS. For example in a streaming service is important that jitter delay and packet loss rate have not to be too high to don't waste communication quality. In our proposal three common parameters have been considered to be QoS parameter to take into consideration into route finding process, they are: The End-to-End delay, the minimum Guaranteed bandwidth and the cost minimization.

Among these QoS parameters the End-to-End delay and the minimum guaranteed bandwidth have to be considered as constrained, instead the cost is a parameter to be optimized. A better resources management permits to allow a higher number of connections, permits to reduce packet loss ratio and permit to reduce delays on the network. As previously described it is important to consider the right QoS constraints that better fit applications type that the network has to distribute for the multicast session.

The respect of QoS constraints drive us to formulate a problem that is well known in literature as a STP. This class of problem is NP-Complete and it is not possible to solve it using polynomial algorithms. This means that is not possible to find optimum with the limit hardware that is available on the router and it is not possible to find solution in a reasonable time. Therefore, an alternative way that is represented by the meta-heuristics has been followed.

Taking into account the definition given in eq. 2.4it is possible to define a multicast call as defined in eq.2.11

$$C = (S, D, MAXDELAY, MINBANDWIDTH) \tag{2.11}$$

in which MAXDELAY is the QoS constraints related to the end-to-end delay, MINBANDWIDTH is the minimum available bandwidth that must guarantee along each path between sources and destinations. as defined into eq. 2.3. At last the multicast tree must respect following conditions

$$\begin{cases} V_T \subseteq V,\ E_T \subseteq E \\ s \in V_T, M \subset V_T \\ B(T(V_T, E_T)) \geq MINBANDWIDTH \\ \triangle(T(V_T, E_T)) \leq MAXDELAY \end{cases} \tag{2.12}$$

2.5 Conclusion on chapter 2

In this chapter the QoS multicast has been faced. In particular the QoS problem has been formulated and all considered constraints have been treated considering the Hierarchical Multilayer network, which is composed of an OBP satellite, a HAP mesh and a network of RCSTs. The reference architecture is a DVB-RCS like network where satellite is used to connect HAPs meshes and RCTS terminal nodes too.

In literature several algorithms have been proposed to solve multicast issues and in particular in this chapter have been described algorithms that implements heuristics and meta-heuristics method to solve the NP-Complete problem that they are faced. The complexity of the problem is known in literature as STP. This problem has been described and it is easy to understand that polynomial algorithm cannot be used to solve multi-constraints QoS routing into a communication network, this is demonstrated by the lemma shown in 2.2.2.1 . Some approaches with polynomial algorithm has been proposed but in these algorithms some complexity reductions about QoS constraints have been made to allow polynomial algorithms to be performed.

After that a brief introduction about multicast protocols have been given. As shown for multicast algorithms they well faced the problem but in some specific context and most common protocols do not offer enough feasibility in terms of QoS, in particular when QoS multi-constraints and high dynamic networks have to be considered. For these reasons a new protocol with QoS support that it is capable to interact with proposed multicast algorithms has to been designed to achieve better performances. This protocol will be used on a multilayer hierarchical network that has been previously described.

Taking into account our goal a representation of the network and multicast issues has been given in terms of combinatorial problem. As known each kind of network can be represented by a graph, on which several consideration can be made. In particular, each link is a weighted link where three coefficients are associated to the link. The considered coefficients are the delay, the available bandwidth and the link cost. Therefore, an analytical presentation of the problem has been given, this representation will be used into next chapter to introduce our algorithms that support the multi-constraints QoS.

Chapter 3
Metaheuristics algorithms for QoS optimization

In this chapter the multicast routing issues related to the algorithms task has been faced, taking into account that a telecommunication network can be viewed as a unoriented and weighted graph, then each node represents a router on the network that allows communication among other nodes and between each source and destination pairs. The multicast paradigm that is considered is the one-to-many, which presumes a data distribution from a single source to several destinations. The main goal is to find a multicast tree capable to distribute packets data on the network respecting some QoS constraints. As just declared the multicast tree search process, in a multi constraints environment, is well known as a NP-complete problem, these trees are also called Steiner trees, therefore a STP has to be considered. Due to the complexity class of the problem, it is not possible to apply polynomial algorithms which are commonly used in the networking and in combinatorial field. Herein, several reasons are shown

- Size of the data structures to being allocated should be too expansive for nodes resources.
- Computational time is not compatible with the nature of the problem.
- Polynomial algorithms cannot be used because is not possible to apply them to a STP that cannot be reduced to a lower class of complexity.

3.1 Genetic Algorithms

The GA belong to the meta-heuristics family and they permit to find a solution that is contained into the solution space[26, 15, 28, 39, 17]. First of all a brief description has to be given to understand data structures on which algorithm works. Each node that belongs to the networks has been tagged with an unique numbering process. Multicast trees are coded into one dimensional data structure where each node is represented by a gene.

GAs are used to solve optimization problem based on evolution principle. GAs use three kind off basic operations that are Selection, Crossover and Mutation. These are used to create a new generation starting from an initial population.

Reproduction is based on darwinian process, and allow us to find, during iteration steps, a new population that ever more fit the QoS constraints, the iterations are performed until a convergence status is not reached or until a prefixed number of iterations are not executed. The crossover operator can achieve sons, which are extremely different from their parents, this allows us to move into solution space in a widely manner but can also avoid to converge towards a solution. For these reasons better parents or chosen parents can survive from an iteration to another one, this is made to do not lost better solutions allowing convergence and finding an admissible solution.

The mutation acts on a single gene of an individual according to a mutation probability. This allows us to avoid sub-optimal local traps. After these changes the resultant population can contains disconnected tree due to unreal link into solution. At the last phase the disconnected tree are find and the new branches are find to find a not disconnected tree.

These techniques do not assure that the found solution is the optimum but with an opportune tuning phase is possible to identify those solutions close to the optimum one. The GAs, in fact, work on a coded data structure of the network nodes, a mono-dimensional data structure is used as genome of the individual.

Using some genetic operators, GAs generates new individuals starting from an initial population found with a random algorithm. GAs triggers genetic operators among the iterations until the max number of iteration is reached. Changing some probabilities and the number of elements that survive between generations it is possible to move into the solution space in different manner avoiding to remain trapped in some local optimum cages. Moreover, changing these parameters it is possible to converge or not towards a solution.

In this state flow diagram is shown as Genetic Algorithm works. In particular it starts from a initial population and once each individual has been evaluated a finite loop is started. In this loop the population evolve in order to find a solution. As further described in this loop the genetic operators work, moreover, these operators permit to converge and avoiding local optimum traps exploring the solution space.

Better is the tuning phase and better these operators work. For these reasons several tuning campaigns have been conducted on the networks with different configurations, topologies and loads.

Let us to explain with more details the genetic operators and show how they work. In further paragraphs algorithm will be described, also our proposals will described further. At the end simulative campaigns will be depicted in order to carried out algorithms results and a comparison between Metaheuristics will be given.

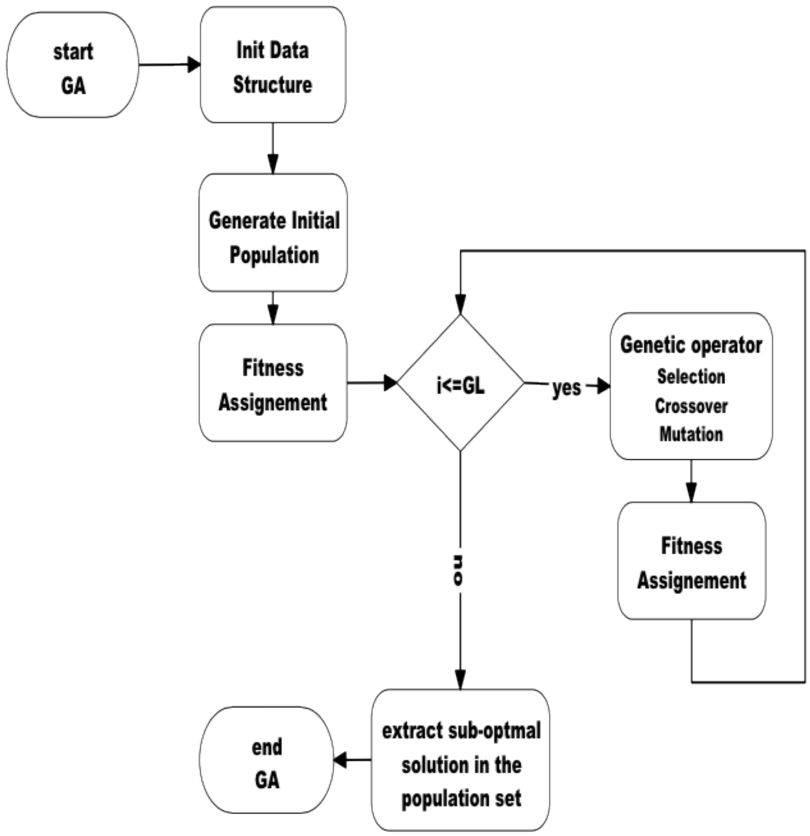

Fig. 3.1 Genetic Algorithm Flow Chart

3.1.1 Coding and Decoding of the Multicast Tree

The multicast tree coding and decoding phases represent a key factor in order to work with simple data structure that help us to reduce problem complexity and permitting to save memory and time resources. First of all network has to be reduced to a graph as described into chapter two. Once the graph is achieved the procedure of node tag is triggered. In this way each node is easy identified and it can be addressed easy. Coding allow us to work on a mono-dimensial data structure that can reduce the complexity of genetic operators. In this work the prufer coding has been chosen, it allow us to code a network with a linear algorithm [38].

The pseudocode of the prufer code is herein shown

The achieved array represents the chromosome that will be used by the algorithm. After that steps the achieved tree has to be decoded. in this first attempt a connected tree is achieved, but as we are going to demonstrate

Algorithm 1 Prufer Code

```
short* coding(Tree T, short size) {
  boolean sourceIsFound = false;
  short leaf,parent;
  short codedTree[size];
  short idx = 0;
  initArray(codedTree,0);
  while(sourceIsFound ==  false)
  {
      Leaf = Search_Minimum_Leaf_Tag_Node(T);
      Parent = Search_Leaf_Parent(Leaf);
      put_Parent(codedTree,idx);
      idx++;
      if(parent == source)
      {
         sourceIsFound = true;
      }
  }
  return codedTree;
}
```

Algorithm 2 Prufer Decode Algorithm

```
Tree* decode(short* codedTree,short size)
{
   Tree T;
   short lackNode[size];
   short label;
   initArray(size,0);
   build_Appo_Array(lackNode,codedTree,size);
   while(hasMoreLabel(codedTree,size))
   {
//get less label and remove it from array
      leaf  =  getLabel(lackNode);
//get first label of the array, remove it and
//if it is not more present into array
//put it into lackNode at first location
      label = getLabel(codedTree);
   }
}
```

further, often after a genetic operators the achieved population is composed of disconnected tree. Therefore a modified version of the prufer will be provided.

The decoding algorithm is even linear and it starts from a coded array then a second array is built and it contains all those label that are not present into the coded array. Herein the pseudocode is given.

Algorithm 3 Initial Population Algorithm

```
Initial_Population(int source)
{
    List <int> neighbours;
    Int x = currentNode;
    List<int> neighbours;
    Topology(x,neighbours);
    int nNeihbours = neighbours.length();
    int k ;
    for(1<=k<=nNeihbours)
        List <int> chosenNeighbours(k);
        for(int i =1;i<=k;i++)
            neighbours.AddNode(chosenNeighbours.getElementAt(i));
}
```

3.1.2 Starting Population

Population is composed of several chromosomes also called individuals, each chromosomes is composed of $n-1$ genes that are the label of the network nodes. Choosing of initial population is important because it acts on the goodness of the found solution and on the convergence time. Generally exist two modalities to achieve initial population

- In the Random mode starting population is chosen in a completely random way, in fact, each chromosome is composed in a random mode. Often chosen chromosome could not be a real solution because they do not belong to the solution space, in these individuals some unexistent links can be used. Using this approach the convergence time is longer than other possible modality. Due to generation modality, several disconnected trees are found, but the advantage of this approach is that it is possible to move in a wider range of the solution space[35].
- Spanning Tree mode permits to find several possible solutions that could belong to the solution space, in this case the convergence time is reduced but the solution space search is limited. In order to search in a widely space then the Genetic Operator probability has to be higher, this allows us to look for a solution in a greater area of the solution space but sometimes could not be possible to converge [55].

In this work a second approach has been considered but in order to better move into solution space new algorithm has been proposed (see 3)

This algorithm is linear and allows us to start from a set of solution that belong to the solutions space and that are spread around all solution space. This method takes advantages by both approaches previously described and allows us to start from different point of the solution space having the possibility to reduce transitory phase because all individuals belong to the solution space.

3.1.3 Multicast tree reconstruction

From the previous phase it is possible that found trees are not connected due to lack of some links[16]. Found tree $T(V_T, E_T)$ has to be a subset of $G(V, E)$ for this reason an algorithm that cleans T from the unreal links has to be applied, in a second phase the disconnected tree has to be improved adding links that allow T to be connected

The algorithm makes the following steps:

1. Find inexistent links that are in T but not in G $E_T^{'} = E|E_T$
2. Remove from T all links that belong to the $E^{'}$subset, at this point several subTree are find $(T_1, T_2, .., T_p)$
3. Find a link in G that connects two ore more subTree
4. Repeat step 3 until all subTree are connected and the tree $T(V_T, E_T^{\prime})$ is found.

Step 3 presents a cycle that has the main task to connect two subtree. In order to do this exist two approaches that allow to find a connected tree that is a subset of G.

- Given two subtree T_i, T_j in a random mode, two subset of nodes $s_i \subset V_{T_i}$ and $s_j \subset V_{T_j}$ are chosen. The algorithm search for a link that connect $u \in s_i$ with $v \in s_j$ or viceversa into G.
- Given two subtree T_i, T_j in a random mode, a heuristic algorithm is used to find a connection of the subtree. For each node is computed the number of branches where it is connected. After that nodes are sorted following an ascendent priority order. Nodes with lower branches have higher priority than other. Considering T_i node with higher priority is chosen as first and a node in T_j is also chosen, at this point all nodes that belong to T_j are considered and a link in G that allow connection between this two nodes are searched. If no connection is possible then second node in list is considered to be the junction node. To better understand the algorithm a pseudocode of the algorithm is depicted in algo. 4

3.1.4 Fitness Assignment

The fitness function assume a privileged role because it assigns to each individual that compose the population a value that represents how the individual fit the problem taking into account the objective function[26, 29, 16].

In fitness assignment the penalty mechanism is adopted, further, more details will be given about the penalty technique.

Taking into account that we are going to consider a multi-constraints problem formulation, therefore a fitness function must have a terms related to each constraints.

Algorithm 4 Junction Trees algorithm

```
Tree junctionAlgorithm(Tree T1,Tree T2,Graph G)
{
   List<short> sortNodeT1;
   List<short> sortNodeT2;
   Tree T3;
   T3 = T1;

   short currNodeT1 = 0;
   short currNodeT2 = 0;

   short idx = 0;

   sortNodeT1 = orderTreeNodes(T1);
   sortNodeT2 = orderTreeNodes(T2);

   currNodeT1 = sortNodeT1.getElementAt(idx);

   while(currNodeT1 != null && treeIsConnected(T3) == FALSE)
   {
      idxT2 = 0;
      currNodeT2 = sortNodeT2.getElementAt(idxT2);
      while(currNodeT2 != null)
      {
        if(linkExist(currNodeT1,currNodeT2) == TRUE)
        {
           mergeTree(T3,T2,currNodeT1,currNodeT2,G);
        }
        else
        {
          idxT2++;
        }
      }
      idx++;
      currNodeT1 = sortNodeT1.getElementAt(idx);
   }

   return T3;
}
```

Fitness function is herein depicted:

$$F(T(V_T, E_T) = \frac{a}{cost(T(V_T, E_T)} * DelayComp * BandComp \tag{3.1}$$

$$\Phi(z) = \begin{cases} 1 & if\ z \leq 0 \\ 0 & otherwise \end{cases} \tag{3.2}$$

$$\triangle_{s,D} = \prod \left(\Phi \left(Delay(T(V_T, E_T)) - MAXDELAY \right) \right) \tag{3.3}$$

$$\mu_{s,D} = \prod \left(\Phi \left(MINBANDWIDTH - Band(T(V_T, E_T)) \right) \right) \tag{3.4}$$

3.1.5 Genetic Operators

The Genetic Operators allows sharing population characteristic in order to achieve better individuals, which are better adapted to the optimization problem

$$P_i = \frac{F(T(V_T, E_T)}{\sum_{j=1}^{popsize} F(T(V_T, E_T)}, \forall i \in 1..popsize \tag{3.5}$$

Selection The Selection is a genetic operator that allows us to operate with the current population in order to produce further individuals. It operates selecting a group of individuals from the current generation based on fitness assignment. Using elitism technique, in order to avoid local optimum trap and convergence issues. Selection permits to a fixed number of individuals to directly pass into next generation[23]. In order to do a selection, a probability is assigned at the start of the internal loop of the algorithm to evaluate current population. To achieve better performance the tuning campaigns have permitted to found the right value for the selection. In fact, selection probability allow us to navigate inside the solution space searching for a sub-optimal solution. Selection probability is shown, in the eq. 3.5 where pop-size is the size of the population set.

Crossover The crossover operation is another genetic operator and it acts on the population mixing their characteristics introducing some mutation to the achieved population. This allows us to better move inside the solution space, but also is not guarantee to find an admissible solution. Crossover takes as input the chosen population that came from the selection operator and make its work chosen each time two parents to generate new individuals. Take into account that the number of individuals that compose the population have to be constant during the algorithm time life. In order to avoid convergence problem and to achieve admissible solution the mutation probability does not be too high and a limited number of genes have to change when new individual is created. The crossover method that is used inside our algorithm is the one point crossover. It merges two chromosome characteristics starting from a choosing point of the chromosome. In it is shown

Algorithm 5 One Point Crossover

```
void crossOver(individuals* parents,individuals* child)
    int n = parents[0].lunghezza();
    int swap_point = Random(1,n);
    int w = 1;

    while(w<=n)
    {
       If(w<=swap_point)
       {
         child[0][w] = parents[w];
         child[1][w] = parents[w];
       }
       Else
       {
        child[0][w] = parents[1][w];
        child[1][w] = parents[0][w];
       }
       w++;
    }
}
```

as the operator works. In the crossover phase the chromosome, which have higher value of fitness are chosen, the crossover point is chosen randomly. Two new individuals are made and they are put in the new set of individuals that compose new generation. in case of odd individuals that compose parents set, the last individual is directly passed into next set. Herein crossover algorithm is shown :

Mutation The mutation is the second genetic operator, which is trigged in bases of a mutation probability that is set at the beginning of the algorithm. Mutation is not less important than the crossover, it permits to extend search of the possible solutions widely into the solution space avoiding to search solution only into a local area of the solution space. The mutation works on all current set and for each step generates a random gene that will be changed with one of current individual in a random position of the individual's genome. Mutation works in this way, chosen an individuals all genome is scanned. A random number is generated and in case of this number is lesser than the mutation probability then the chosen element of current chromosome is changed with an another one that belongs at the set of the node of the $G(V, E)$; therefore the overall algorithm is herein shown:

Algorithm 6 Mutation

```
void mutationOperator(individuals chromosoma)
{
    float n = Random (1,100);
    n = n/100;
    short E_T(chromosoma.size());
    short mutationPosition = Random(0,chromosoma.size()-1);
    short node;
    E_T = getChromosomaNodes(chromosoma);
    if(n < GetMutationProbability())
    {
        node = GetANodeFromAvailableNode(E,E_T);
        chromosoma[mutationPosition] = node;
    }
}
```

3.1.5.1 Disconnected Tree Issue

When genetic operators work on a chromosome, it is possible that a disconnected tree is generated. In this cases a tree reconstruction algorithm has to be designed in order to achieve a connected multicast tree that allow us to cover all destinations of the multicast group. In order to do this a match between solution network links and real connections that are available on the network topology has to be achieved. In case of disconnected tree it is possible that at least an edge verifies the eq. 3.4

$$\exists e \in E_T, e \notin E \tag{3.6}$$

the reconstruction algorithm is herein shown and it allow us to achieve a connected multicast tree

3.1.5.2 Convergence Issues

In order to allow algorithm convergence, it is important to configure in a right manner the algorithm parameters. This can be made only throught several tuning campaigns that are used to understand the behavior of the algorithm in different case of uses. This allow us to find right parameters in order to

- Converge towards a solution;
- Reduce transitory time;
- Find a solution that belongs to the solution space;
- Find a good solution, which is not so far from the optimum;

Algorithm 7 Reconstruction Tree Algorithm

```
Tree treeReconstruction(Tree T)
{
  list <Tree> A;
  A = achieveDisconnectedSubTree(T);
  int nDisconnectedTree = A.length;
  int idxTree = 0;
  int innerIdxTree = 0;
  while(nDisconnectedTree > 1)
  {
    A1 = firstDisconnectedTree(A);
    for( idx = getFirstNode(A1);
         idx < A1.nNodi() && !found;
         idx = nextNode(A1,idx))
    {
         A2 = getNextTree(A,idxTree);
         innerIdxTree++;
         while(!A2.isEmpty() && !found)
         {
             found = findConnection(A1,A2,idx);
             if(!found)
             {
                A2 = getNextTree(A);
                innerIdxTree++;
             }
         }
         idxTree++;
     }
  }
}
```

3.1.5.3 Genetic Algorithm results

In this section we are going to show how the proposed solution outperforms the others meta-heuristics and the distance between the GA solution and the optimum one. The optimum has been found considered an exhaustive search on the same network.

3.2 Broadcast gain

In order to enhance the overall performance of the GA a new cost concept has been introduced taking into account the network architecture. The network, just described into chapter two, has the main characteristic to cover a wide range of area with a single spot or beam.

In fact, both satellite and HAP can cover several terminals that connect several multicast groups using their interfaces. In this new release of the algorithm shall be advantaged those nodes that can cover a higher number of terminals in fact the cost parameters is directly connected with the number of covered terminal. In this way it is possible to reduce the number of packet that travel on the network without waste the performance of the services. Let us to explain the algorithm in details. Each node belongs to a different layer family.

The proposed broadcast technique is called Broadcast Gain (BG) metric. This new concept of multicast metric allow us to achieve a better network resource management. The proposed algorithm goes to mainly utilize those links that are capable of covering a greater number of terminals. BG metric can be used in a generalized wireless network where it is possible to take advantage of different node densities. In particular, in this algorithm the fitness and penalty functions were modified.

Thanks to the new proposed functions, solutions that do not respect the imposed constraints, will be discarded with higher probability, because they will have a more penalized fitness function. In order to take advantage of the aforementioned algorithms a new GA is proposed. It is called Hybrid Cost Delay Bandwidth – Genetic Algorithm (HCDB-GA). The BG concept is to guarantee a distributed use of the network resources between the multicast groups that are active in the network. As the Previously proposal, new algorithm respects the imposed bounds, but it exploits broadcast nature of the reference network. The CCDB-GA requires a shorter time than the HULK-GA to find a solution closer to the optimum one, but it does not consider the possibility of using shared resources, in order to optimize the link cost per user. Moreover, it does not consider the network resources distribution through the multicast groups.

With the BG the HULK-GA look for a solution where a network node can cover more terminals, in this way the total cost of the link can be shared between users. Let us to define the sets to be used in this section. In particular, the user set indicated with the D term is defined, n is the number of the end-user routers into the network. These routers supply connectivity for the user and permit the end-user to achieve network access. Following the algorithm formulation is shown, starting from the definition of the nodes set dived by class of Node.

$$D = \{d_1, d_2 d_3, .., d_n\} \tag{3.7}$$

Hap set is composed of all HAP node and its cardinality is m, a definition of the set is herein shown

$$H = \{h_1, h_2, h_3, ..., h_m\} \tag{3.8}$$

Satellite node is indicated as S and of course its cardinality is 1.

In order to define the BG it is important to define the overall multicast tree cost that is given by the sum of links among the different sets previously defined. Thus an analytical formulation is given, first of all each cost contribute is herein shown:

- C_D^H cost — is the cost of the link between a generic HAP and a generic end user access router
- C_D^S cost — is the cost of the link between the satellite node and a generic end user access router
- C_H^H cost — is the cost of the Inter - Hap link (IHL) between two connected HAPs
- C_H^S cost — is the cost the link between the satellite and a generic HAP
- C_H^D cost — is the uplink cost of the link between a generic end user access node and the HAP node
- C_S^D cost — is the uplink cost of the link between a generic end user access node and the Satellite node
- C_S^H cost — is the uplink cost of the link between a generic HAP node and the Satellite Node

Some law that regulate the relationship among the cost terms have to be given, and they are available in the following :

$$C_S^H < C_D^S \tag{3.9}$$

$$C_D^H < C_H^S \tag{3.10}$$

$$C_H^S < C_D^S \tag{3.11}$$

Each Cost Term is now unfolded in details.

$$C_D^H = \sum_{i=1}^{m} \left[\frac{\sum_{j=1}^{n} C_j^i}{n - n_1} \right] \tag{3.12}$$

in the eq. 3.12 the n_1 is the number of the end-user access router that are not currently connected with the $i - th$ HAP. Moreover, the cost related to those nodes that is not connected with the $i-th$ HAP will have the following value

$$C_j^i = 0 \Leftrightarrow \forall i \in H, \forall j \in D \ (i, j) \notin V \tag{3.13}$$

$$n_1 = |\{(i, j) \notin V | i \in H, j \in D\}| \tag{3.14}$$

In the eq. 3.15broadcast cost between the satellite node and the end user access routers have been shown

$$C_D^S = \frac{\sum_{i=1}^{n} C_i^S}{n - n_2} \tag{3.15}$$

$$C_j^S = 0 \Longleftrightarrow \forall j \in D\ t.c(S,j) \notin V \tag{3.16}$$

$$n_2 = |\{(S,j) \notin V | j \in D\}| \tag{3.17}$$

The IHL cost is given by the eq. 3.18

$$C_H^H = \sum_{i=1}^{m} \sum_{j=1}^{m} C_j^i \tag{3.18}$$

$$C_j^i = 0 \Longleftrightarrow \forall i, j \in H, (i,j) \notin V \tag{3.19}$$

The Satellite-HAP cost is given by the eq. 3.20

$$C_H^S = \frac{\sum_{i=1}^{n} C_i^S}{n - n_3} \tag{3.20}$$

$$C_j^S = 0 \Longleftrightarrow \forall j \in H, (S,j) \notin V \tag{3.21}$$

$$n_3 = |\{(S,j) \notin V | j \in H\}| \tag{3.22}$$

Finally, the total cost of a generic multicast tree that belongs to the solution space

$$C(T) = \sum_{i=1}^{n+m+1} \sum_{j=1}^{n+m+1} W(i,j) \quad \forall (i,j) \in V_T \tag{3.23}$$

$$C_{TOT} = C_D^H + C_D^S + C_H^H + C_H^S + C_H^D + C_H^S + C_S^D \tag{3.24}$$

Therefore it is possible to achieve the BG, which is given by the

$$BG(T) = \frac{C_{TOT}}{C(T)} \tag{3.25}$$

The BG-GA is also called HULK-GA and it is different from the previously one by the cost contribute that in this case is given by the eq. 3.25

3.2.1 Hybrid Algorithm

In order to take advantage of the proposed technique a hybrid algorithm can be adopted that combines our previously proposed algorithms with the

BG. This proposal, called HCDB-GA, can consider both fitness functions obtaining a new fitness function.

This fitness permits resources optimization to be obtained, moreover, it allows better solutions in terms of end-to-end delay and available bandwidth along the path from the multicast source towards all multicast destinations. HCDB-GA fitness function is given in eq. 3.26

$$h_1 * F(CCDB - GA) + h_2 * F(HULK - GA) \tag{3.26}$$

Where h_1 and h_2 are two weight coefficients used to achieve a new fitness function that merge the effects of the previously proposed algorithms. Acting on these terms it is possible to obtain a different behavior of the GA adapting itself at the applicative scenario. The coefficient have to respect the eq. 3.27

$$\begin{cases} h_1, h_2 \leq 1 \\ h_1 + h_2 = 1 \end{cases} \tag{3.27}$$

If a solution that is closer as possible at the optimum solution then the $h_1 > h_2$ coefficients configuration has to be used, in this way the best solution in terms of QoS constraints is found. Instead if we are looking for an admissible solution that focus on network resources optimization then the configuration $h_2 > h_1$ can be used, also in this case is guaranteed that the found solution widely respect the imposes bounds on multicast constraints if it exist. In order to find a solution that both consider resource optimization and QoS optimization then a good trade-off between coefficients has to be found.

3.3 Simulated Annealing

SA is a newest meta-heurstic that is carried out from the metallurgic field [20, 24]. In particular it exploits the law of metals that solidify in ordered or chaotic structure following the temperature trends. A faster temperature reduction generate a chaotic structure because the atoms have no time to organize into ordered crystals. Instead, when the temperature reduction is not faster the atoms can organize itself in a ordered manner. Moreover, a higher temperature means higher kinetic energy that it is used by the atoms to move and collide. Exploiting the temperature proprieties and kinetic energy concept. Thus, an algorithm that can reproduce these behaviors in the routing scenario has been designed. As made for genetic algorithm the network topology has to be coded into a structure that can be used to represents network nodes.

SA is a meta-heuristic method that permits a sub-optimal solution to be found in the solution space. It takes advantage of the metallurgic field and it moves into solution space changing the current solution proprieties. It has proven to be a simple but powerful method for large-scale combinatorial optimization. SA permits the inner Energy of the solution to be changed, increasing its temperature. Higher is the temperature, higher is the possibility of changing several characteristics of the current solution. However, the temperature decreases with the augment of the algorithm iterations; this means that less change is admitted on the solution. If the temperature drops quickly, the molecules solidify into a complex and not ordered structure. However, if the temperature drops slowly, they form a highly ordered crystals. The molecules of a crystal solidify into a minimal energy state.

The SA starts with a base solution, this one can be obtained using a well-know algorithm such as Prim's algorithm or Dijkstra's algorithm; This solution can be not an admissible solution because it could not satisfy some of QoS constraints. Once the base solution is found then the algorithm can perform its iterations and it can explore the solution space. SA core is rule by temperature function and an inner energy function.

Energy function evaluates the solution pools and gives a value to each solution. The algorithm moves into the solution space generating neighbor solutions. These solutions are obtained changing some characteristics of the current solution; these changes influence current solution proportionally to the current temperature. The SA could be trapped into some local optimum cage and no others solutions could be explored. In order to avoid this possibility, the considered SA can take advantage of the uphill method.

Uphill permits the current solution to be changed with a new one from the solution admissible set, this last solution is not the best; therefore, this replacement allows exploration of a new point in the solution space. This method was described by S. Kirkpatrick, C. D. Gelatt e M. P. Vecchi and then it was represented by V. Černý. The Metropolis [59] criterion attempts to permit small uphill moves while rejecting large uphill moves. This is to prevent the algorithm from becoming stuck in a local minimum.

In the following a pseudo code of an SA main procedure implementation is shown. SA can also be used in telecommunications such as GAs, Tabu Search methods or other meta-heuristics, in order to solve optimization problems such as best QoS multicast tree construction.

According with [20, 11] the SA has been considered in our multicast protocol for comparison purposes with the proposed GA based multicast.

3.3.1 SA Algorithm details

In this section the SA algorithm is described in details. The SA performs three steps that are herein shown

1. The first phase of the algorithm is used to initialize parameters such as initial temperature, initial solution and init of the Evaluating Function

Algorithm 8 Simulated Annealing algorithm

```
x_0=Prim(source,G);
x_best=x_0=x_now;
iteration=0;
t=initialTemperature;
while(iteration<MaxIter)Do
  count=0;
  while(count<MaxCount)Do
                NeighbourGeneration(x_now,t,population);
                RandomSelection(x_j,Neighbours);
        delta = getEnergyEvaluate(x_j)-
                getEnergyEvaluate(x_now);
                if (delta<0)then
                        x_now=x_j;
                        if(getEnergyEvaluate(x_now)<
               getEnergyEvaluate(x_best) then
                                x_best=x_now;
                count=0;
                    else if changeSolution(delta,t) then
                                x_now=x_j;
                count++;
            end if;
   end of while loop(inner iteration)
   iteration++;
   t=temperatureUpdate(t);
end of while loop (outer iteration)
return x_best;
```

2. The second phase of the algorithm generates several solutions that are neighbor of the initial solution. This changes are made taking into account temperature values.
3. The third phase evaluates a solution that is picked up from the previous set of solutions and it is evaluated and a comparison with the current is made. If the solution is better than the current, this solution is taken as current. There is another possibility that the solution is taken as current, in details following the uphill law, if it is made, the exchange is made. The probability depends of the temperature value.

The first phase is executed at once, instead the other two phases are executed in an iteration way fixing a determinate number of steps to made.

3.3.1.1 Algorithm coding

In order to work with easy data structure a coding algorithm is needed. One of the most common used coding is the binary code where a solution is represented by a bits array. In this code each bit is a node of the network and high value indicates that the node is presented into solution, low value indicates that the node does not belong to the solution see Figure 3.2. Moreover, the size of the array is equal to the size of the network node's set.

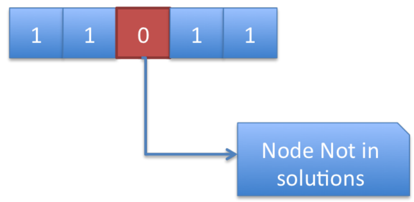

Fig. 3.2 SA Binary code

Acting on this solution it is possible to change each single bit generating several solution. The output could not be a tree but tree forest because solution branches could not be exist. For this reasons when a change is made the it is important to check if a solution is admissible or not. In case that the solution is not a connected tree it is dropped. This algorithm is easy but is hard to rebuild multicast tree and information about overall network have to be used.

Fig. 3.3 SA Path coding

Another kind of coding is the path coding that allow to codify solution with paths see Figure3.3. In other words each element of the array is a complete path that indicates the route from the source to a destination. In this case the neighbors search is made exchanging a path with another admissible path. In this case it is not needed a check on found solution but this method is most complex than the previous one because for each change a path computation have to do in order to find a set of admissible paths.

In our proposal another kind of code is used, it is proposed a new coding method that allow us to simplify the process and reduce the complexity of the algorithm. Solution is represented by an integer array where each element is a node of the network, but in a generic cell of the array at the index i, there is those node if that allow us to reach the node i, see Figure3.4.

The source of the multicast source, which is the root of the solution has not node that reach it, therefore in its position is set a 0. In case of nodes that not belong to the solution their cell value is -1. In this way it is easy to rebuild multicast tree, but it is necessary to check if the achieved solution is a connected tree or not.

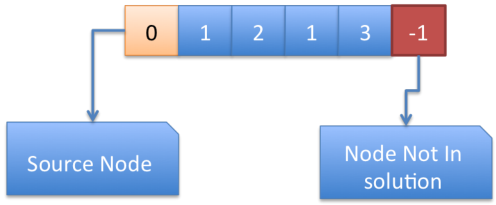

Fig. 3.4 SA coding proposal

Neighbor solutions are easy achieved, coding algorithm is shown. Neighbor solution is generated starting from current solution and changing some elements of the solution. In order to achieve new solution some rules have to be respected

- Only an element can have 0 because multicast tree has only one source (paradigm one to many)
- Cell of the array that have as index a destination cannot have -1 as value, because all destinations have to be reached with a path
- The array have to be loop free, otherwise disconnected trees are generated. In other words the follow case is not allowed

Fig. 3.5 Solution with loop, which is not allowed

- Solution where a destination is reached by a node that it's not in solution is not allowed. considering a solution with two elements the following case is not allowed

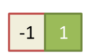

Fig. 3.6 not allowed solution due to node presence into solution

At the end of neighbor generation a check about tree consistent has to be made. This is made building the tree and performing a view of the tree.

Algorithm 9 Neighbor Generation Algorithm

```
void neighbourGeneration(individual x_now,
                         short populationSize,
                         individual* neighbours)
{
   short i = 0;
   individual x;
   for(i = 0; i<populationSize; i++)
   {
      getNewSolution(x_now,&x);
      if(isATree(x))
      {
               neighbours.add(x);
      }
   }
}
```

3.3.1.2 Neighbors Generation

In this section, neighbor generation algorithm is focused. As previously depicted neighbor generation is an important point because the goodness of the found solution is directly connected with this generation step. The algorithm receives as input current solution and the number of elements of the population to generate.

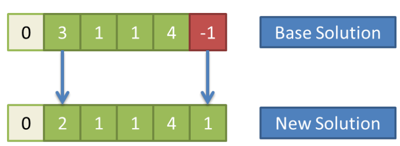

Fig. 3.7 Neighbor Generation Process

This procedure is composed of a main loop with n iteration, where n is the number of element that compose the population. This procedure for each iteration calls another procedure that has the task to achieve a mutation over the current solution. This procedure is called getNewSolution. Solution achieved is then checked to verify if it is a feasible solution and a consistent tree. If check is passed solution is putted into solution set and next iteration is made.

Herein the pseudo code of the algorithm is given.

3.3.1.3 New solution algorithm

At each iteration the algorithm generates a new set of neighbors solution that are used to explore the solution space. A generated solution is called neighbor because it is achieved from a base solution through some mutation. It is important to choose in a correct manner the number of elements to being change because the goodness of the solution space exploration depends by this step. As previously said the number of mutation directly depends of system temperature. An higher number of changed element means a higher free degree but the probability to have a disconnected tree also increase.

When neighbors generation routine calls the getNewSolution procedure then this procedure has the task to generate a new solution starting from the base solution, which is passed as an input parameter. New solution is achieved taking into account overall system temperature. In case of mutation then the mutation position is chosen randomly. Mutations number as said depends of the temperature, in particular higher is the temperature higher are the number of mutations to do.

In the inner loop three possibility can be happen following the index of the array to change, these are herein depicted

source — if the index is the source index iteration is not performed and next iteration shall be performed

destination — if the index belong to a destination, then following the rules of the generation process the admissible values have to belong to the following set $x[pos] = random([0..n])$

node — If the index belong to a generic network node then the $x[pos] = random([-1..n])$

3.3.1.4 Inner Energy Function

The inner energy function is used by the algorithm to make solution comparison in order to carry out the solutions. During the heating of a metal process the main goal is to achieve a final inner energy that is lesser than the initial, because an increased stability of the internal atomic structure is looked for.

What we are looking for is a function that has an inverse functionality, in other words we are looking for an objective function that, at the end, has a higher value than the initial state. Therefore, solution that has higher values than others mean that are better than others.

The objective function is much important because it determines the goodness of the algorithm during the search process, and it helps us to search in a right manner finding at each iteration the better solution. Main goal of the algorithm is to satisfy QoS requirements, which are requested by the users. The objective function is based on a multi-constraints requirements as made

Algorithm 10 Neighbor generation algorithm

```
void getNewSolution(individual x_now,individual* x)
{
        *x = x_now.clone();
        short numberOfMutaion =
                    getCurrentTemperature() / (100*3);
        short pos = 0;
        short n = x->getLength();
        while(numberOfMutaion > 0 )
        {
            pos = Random(0,n);
            if(pos != sourceIdx)
            {
                if(isADestinationIndex(pos))
            {
              x->array[pos] = Random(0,n);
            }
            else
            {
              x->array[pos] = Random(-1,n);
            }
            }
            numberOfMutaion--;
        }
}
```

for GA. Therefore, the objective function takes into account end-to-end delay, minimum available bandwidth and a cost factor.

Delay terms is given by the eq.3.28

$$\begin{cases} \delta(s) = 0 \\ \delta(i) = \delta(s) + \triangle(s,i) \\ \delta(j) = \delta(i) + \triangle(i,j) \end{cases} \tag{3.28}$$

where s is the source node, i is the next node along the path between the source and the node j. Moreover, $\delta(x)$ represents the delay between the source and the node x, instead the delay between two consecutive node, i and j, is indicated as $\triangle(i,j)$. It is important to recall that $s, i, j \in V_T$ where T is the multicast tree.

At the end the delay contribute is given by the eq. 3.29

$$\gamma = 1 - \frac{\phi(T)}{DelayThreshold} \tag{3.29}$$

where $\phi(T)$ is the maximum delay among source and destination, instead DelayThreshold is the delay threshold that an user can support.

In order to give more details about bandwidth contribute the following formulation have to be given

$$\rho = min\left\{Bandwidth(i,j)\right\} \forall e(i,j) \in E_T \tag{3.30}$$

$$\varphi = max\left\{Bandwidth(i,j)\right\} \forall e(i,j) \in E_T \tag{3.31}$$

Moreover with the B is indicated the transmission bandwidth, at the end the bandwidth contribute is given by the eq. 3.32

$$\begin{cases} \eta = 1 & if \rho = \varphi = 0 \\ \eta = \frac{\rho - B}{\varphi} & otherwise \end{cases} \tag{3.32}$$

At the end the function to evaluate the goodness of a solution is given by the eq.3.33

$$\begin{cases} k_1 * \gamma + k_2 * \eta \\ k_1 + k_2 = 1 \end{cases} \tag{3.33}$$

In order to have different behavior in terms of bandwidth and delay it is important to tune the $k_1$and $k_2$coefficients. In accordance with the eq. 3.33 higher is k_1 higher importance is given to the end-to-end delay requirements. Inverse case is made when $k_2$is higher than k_1, in this case more importance is given to the bandwidth requirement.

3.3.1.5 Temperature Function

The temperature value influences the number of element that at each iteration could be modified. Moreover, also the probability, that a generic solution can begun a current solution, depends from the temperature. At start time the temperature assumes high values, this choice is made in order to give at the algorithm high freedom degree, hence a great number of solutions are explored into solution space. When the temperature decreases the search process is focused in a particular area of the solution space because lesser change are made into current solution. When the algorithm search in a particular area and in order to avoid local optimum cages then the uphill process is innovated.

Commonly a linear temperature law is utilized and it is given by the eq. 3.34

$$t_{k+1} = \alpha * t_k \tag{3.34}$$

In 3.34 the term k in the $k - th$ iteration and α is a real number that belongs to the range [0..1]. This function does not take into account dynamic evolving of the search process and it supposes when the algorithm is near at the end of the prefixed iterations the area where the algorithm looks for

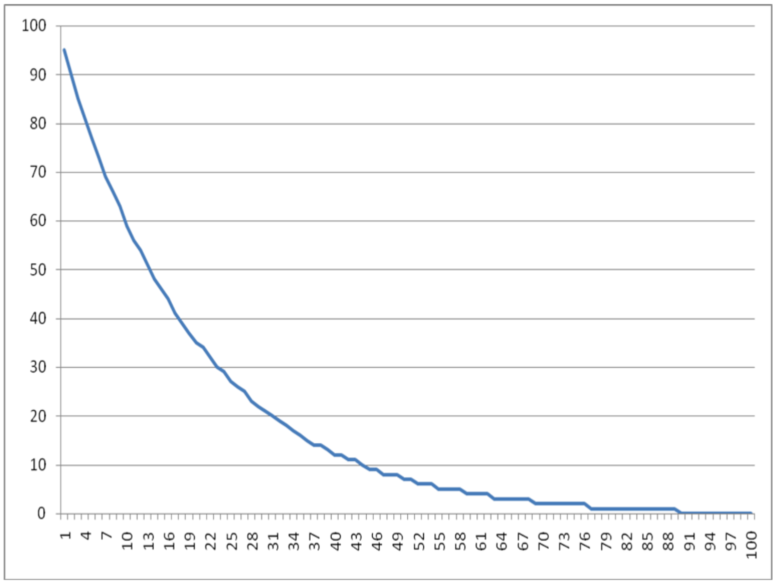

Fig. 3.8 Common Temperature Trend

is those where the optimum is locates. This is not real true because during iteration the algorithm could be focus its search into a local optimum space that avoid to search for the global optimum. To avoid this behavior another temperature approaches is proposed further.

The temperature law, which is proposed, takes into account the dynamic of the search process and adapt the temperature to the state of the current solution. A window mechanism is used to control temperature trend. The temperature law is shown in eq. 3.35

$$t(k) = IniTemp + \left(\frac{1}{e^k}\right) - Norm * e^{(k-ItNum)} - \beta * k \tag{3.35}$$

Here the following term means :

k	is the iteration number
iniTemp	is the initial temperature at it is the starting point for the algorithm
Norm	is a coefficient used to normalize values, and it permits that at the end of the iterations the temperature is around the zero
inNum	is the max number of iteration of the algorithm
β	is the coefficient that it is used to give a slope to the trend of the function. Therefore, it is used to control the decreasing speed of the temperature.

In the following figure the average trend of the function is shown

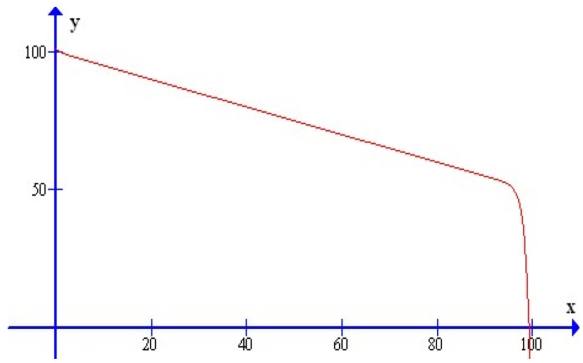

Fig. 3.9 Proposed Temperature law trend

The parameter that make dynamics the temperature is the β coefficient that allows us to control the temperature increasing or decreasing temperature speed. This parameter is controlled by the algorithm taking into account past values of the temperature that belong to a time window that is composed of 5 time samples of objective function.

The slope of the temperature is increased or decreased considering the distance between the current optimum and the average value of the samples. if this distance is greater than a threshold then the slope is decreased in order to permit at the algorithm to search in a greater space. If the current optimum and the average are not too far and the difference is below the threshold the slope is increased because it is supposed that the local optimum is not so far from the global optimum, therefore, a narrow space could be explored to found the optimum avoiding to find disconnected tree or solution that are far from the optimum. In this way the convergence of the algorithm to a feasible solution is guaranteed. Herein the pseudocode of the temperature control is depicted

The window update function allow us to update temporal window in order to maintain updated the sample of the objective function. This permits to correctly update the temperature slope in order to explore in a correct manner the solution space. Its pseudo code is herein reported

3.4 Multicast Algorithm Simulation Campaigns

In this section algorithm some simulative campaigns are carried out. First of all in order to understand the results some parameters definition have to be made. Moreover, other two additional metrics such as Multicast Tree density cost and Optimal Solution Contribution have been also considered in order to account respectively the cost improvement in terms of coverage in the

Algorithm 11 Temperature Control Algorithm

```
temperatureUpdate(short currentIteration)
begin
   if((currVal − average(T_window)) > Threshold3) then
     setSlope(b = b + 0.05);
   end if;

   if ((currVal − average(T_window)) > Threshold2) &&
      ((currVal − average(T_window)) < Threshold3))
   then
        setSlope( b = b);
   end if;

   if ((currVal − average(T_window)) > Threshold1) &&
      ((currVal − average(T_window)) < Threshold2))
   then
       setSlope( b = b − 0.05 )
   end if;

   windowUpdate(currVal);

end
```

Algorithm 12 Window Update Code

```
windowUpdate( real currVal )
begin
        if (size(T_window) < WINDOWSIZE) then
            T_window.add(currVal);
        else
        T_window.removeOlder();
            T_window.add(currVal);
    end if;

end;
```

multicast tree and the distance of the found solution from the optimal one. This last one is achieved computed using an exhaustive search method.

3.4.1 Multicast tree density coefficient

In order to define Multicast Tree Density Coefficient (MTDC) a brief description is needed. This coefficient is used to evaluate the multicast tree capacity to cover all destinations with the minimum number of intermediate nodes. it is given by the eq.3.36

$$(mtdc)^{-1} = \sum_{i=1}^{n}\sum_{j=1}^{n}\frac{1}{w(i,j)} : e(i,j) \in E_T \tag{3.36}$$

w(i,j) is a weight function that is defined as shown in eq. 3.37

$$\begin{cases} w(i,j) = 0.1 & ife(i,j) \in E_T \\ w(i,j) = 0 & otherwise \end{cases} \tag{3.37}$$

in eq. 3.36 and in eq.3.37 V_T is the set of the nodes where $T = G(V_T, E_T)$, instead $n = |V_T|$. $e(i,j)$ is the link that connects node i and node j

3.4.2 Optimal Solution Degree distance

In this section it is shown how the distance degree is computed. In order to achieve the distance degree index the average end-to-end delay along each path between source and destination is taken into account, also the bandwidth and the average cost and total multicast tree cost are taken into account. Therefore, let us to define the Optimal Solution Coefficient (OSC), recall that D is the multicast destination set.

The average end-to-end delay is evaluated as shown in eq. 3.38

$$\overline{\triangle(T)} = \frac{\sum_{d \in D} \triangle_{s,d}}{|D|} \tag{3.38}$$

The average multicast Tree cost is given by the eq.3.39

$$\overline{C(T)} = \frac{C(T)}{|D|} \tag{3.39}$$

For the bandwidth constraints is given the bandwidth term as shown in

$$B(T) = min_{d \in D}(B_{s,d}) \tag{3.40}$$

The QoS constraints upper and lower bound have been just specified into chapter two, but it is important to recall that the μ is the bandwidth lower bound, instead of ϕ, which is the end-to-end delay upper bound. Therefore, the OSC is given by the eq.3.41

$$OSC(T) = \frac{\phi}{\overline{\triangle(T)}} + \frac{1}{C(T) + \overline{C(T)}} + \frac{B(T)}{\mu} \tag{3.41}$$

Finally the distance degree is shown in eq. 3.42, and it is used to evaluate the distance between the current solution and the optimal one. In the eq. 3.42 the T_0 represents the optimal solution, and the sub-optimal solution, which is found using metaheuristc algorithms, is called T_s

$$dis(T_o, T_s) = OSC(T_o) - OSC(T_s) \tag{3.42}$$

3.4.3 GA Algorithm results

In this section a performance study of the proposed GAs will be given in to illustrate their behaviors. In order to evaluate the contribution of the new proposals the trend of the CCDB-GA algorithm was compared with the imposed Delay-Bandwidth versus the trend of the HULK-GA with the same constraints. Moreover, other simulations are carried out in order to evaluate the HCDB-GA performances, in particular and parameters are changed.

In order to perform the following simulations a multi-layer hierarchical architecture was considered where a satellite has the possibility of covering an HAPs mesh and terminals. Moreover, a maximum end-to-end delay of 280 10-3 sec was considered and a minimum bandwidth of 600 Kbps.

In order to compare the GAs performances for the HCDB-GA the following values were used: h1 = 0.5 and h2 = 0.5.

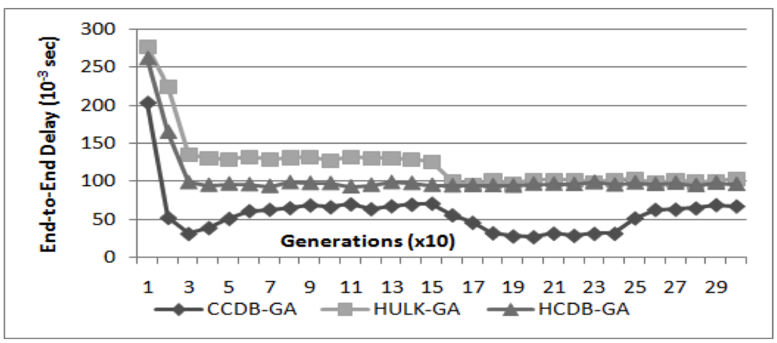

Fig. 3.10 Average End-to-End Delay vs. Generations

In Figure 3.10 the trend of the average end-to-end delay for proposed algorithms is depicted. The CCDB-GA finds a solution that has lower end-to-end delay than other algorithms because it has the possibility of not considering the broadcast and it considers each link as a possible link to route the data flow. With this consideration it is simple to understand that the algorithm can find more paths in order to connect destinations. This consideration implies having a higher multicast tree cost than the other algorithms. Instead HULK-GA and HCDB-GA, in order to optimize the network resources try to cover more terminals with minimum number of intermediate nodes.

This observation is also visible in Figure 3.12 where density coefficient is depicted. In fact, HULK-GA and HCDB-GA have a higher density coefficient than the CCDB-GA.

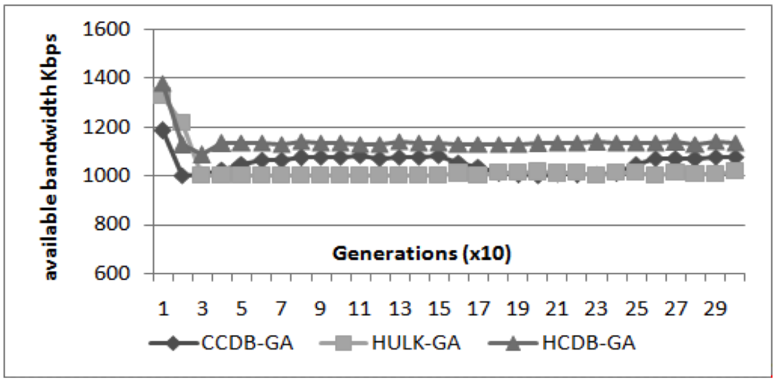

Fig. 3.11 Average available bandwidth vs. Generations

Figure 3.11 shows the trends of the available Bandwidth for the CCDB-GA, HULK-GA and HCDB-GA. In this figure, it is possible to observe that in order to respect the imposed bound on end-to-end delay only a restricted number of solutions can guarantee it. This leads to having close solutions, in terms of available bandwidth, for all considered GAs. Figure3.12 shows the density coefficient representation, when the CCDB-GA, HULK-GA and HCDB-GA are used. The Graph shows that the HULK-GA and HCDB-GA uses a minor number of nodes in order to cover other network nodes. In this way, more link resources are optimized. Moreover, these resources can be shared between the multicast groups that are active in the network.

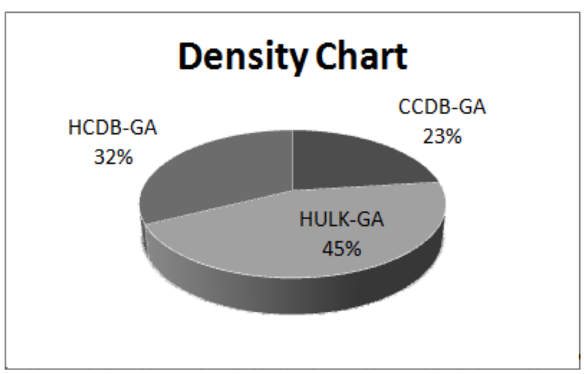

Fig. 3.12 Algorithms solution density chart

In Figure3.13 the end-to-end delay, when coefficient and are changed, is depicted. In order to explain the following figure two acronyms are defined for the fitness function:F1 is the fitness function of the HCDB-GA where and in this way a greater contribution of the HULK-GA fitness function is given. While with the acronym F2 is indicated the fitness function of the HCDB-GA where and in this way a greater contribution of the CCDB-GA fitness function is given. When F1 is considered then the end-to-end delay of the found solution is higher than the other curves, the latter instead shows the solution found when F2 is considered.

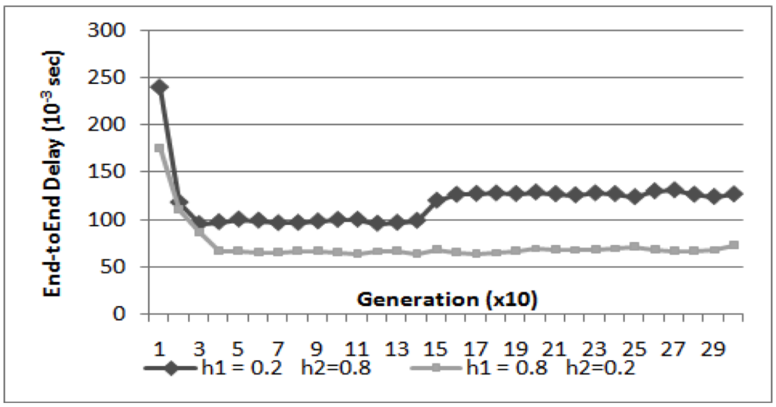

Fig. 3.13 End-to-End delay vs. h1,h2 coefficients variation

Moreover, as is shown in Figure 3.14, a more available bandwidth is given by the F1 fitness function. Moreover, in Figure 3.15 the density chart of the overall capacity of the solution found to cover a greater number of nodes optimizing network resources is shown. In particular, here the density coverage is optimized taken advantages of the broadcast nature of the considered wireless architecture.

In the further Figures a comparison between CCDB-GA and MOGA has been carried out, in order to show the goodness of our proposal. MOGA, in fact is one of the most used and better GA in literature and in the following comparisons it is possible to note how the CCDB-GA outperforms the MOGA.

In Figure 3.16 the execution time related to CCDB-GA and MOGA is shown, it is explicit that the CCDB-GA outperforms MOGA and the fork between times increase with the increasing of the network size, this means that CCDBA-GA is also scalable in terms of network size. In the next simulation the imposed bounds on end-to-end delay has been 300 mms, whereas network size and network topology and load are equal to both algorithm in order to carry out a real comparison between the algorithms. Moreover, since MOGA is designed to find cost and delay optimization, the CCDB-GA

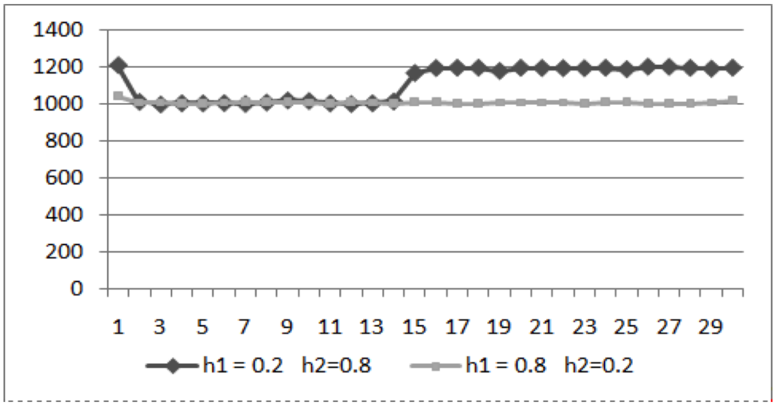

Fig. 3.14 Available Bandwidth vs. h1 and h2 coefficients variation

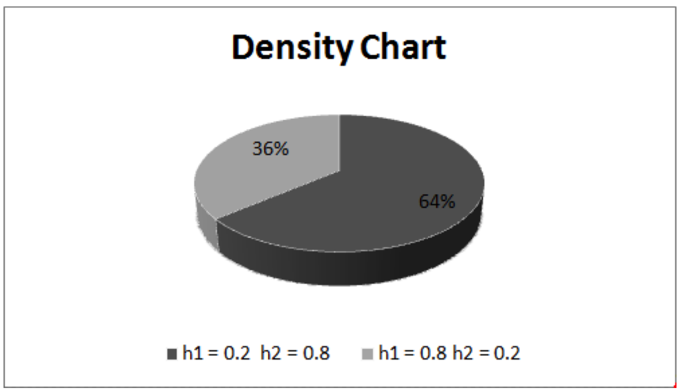

Fig. 3.15 Density chart vs. h1 and h2 coefficients variation

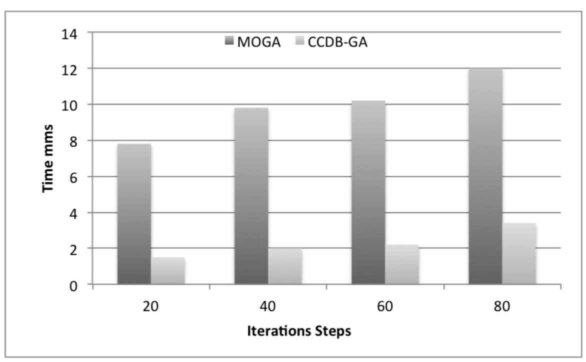

Fig. 3.16 CCDB-GA vs MOGA in terms of execution time

has been configured in modality cost-delay constraint. Where the bandwidth terms is not taken into consideration.

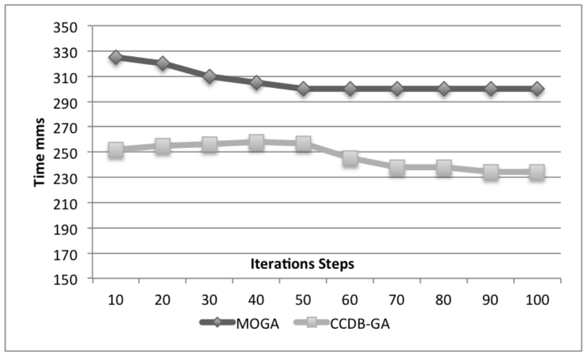

Fig. 3.17 CCDB-GA vs. MOGA - End-To-End Delay at iterations steps

In the Figure 3.17 the CCDB-GA and MOGA have been observed at each iteration steps to evidence how the algorithms search for a solution. MOGA initially presents a transitory time and once it finds a solution that respect the imposed bounds on delay it carries out this solution as the better. The CCDB-GA, instead, show another behavior. It looks for a solution in a wider space of solution than the MOGA and this is demonstrated because initially it founds even better solutions than the MOGA, but these solutions is not the better, in fact the better will be found further after that the penalty function avoid local optimum cage allowing to search for a solution in another area of the solution space. After a certain transitory time, which in this case has been longer than the MOGA, it finds a good solution that outperforms the MOGA. Moreover, in the Figure 3.18 is observed that it is possible to bring up another consideration. MOGA, once finds a solution that respect the bounds on the delay tries remain in trap in a local optimum because as happen for the delay also the cost is not more optimized, instead, for the CCDB-GA also in this case of the cost, the algorithm tries to find a more better solution.

3.4.4 HCDB-GA versus SA Simulation Campaigns

In this section a comparison between two different approaches has been made: HCDB-GA and SA algorithm are investigated in order to observe the algorithms behaviors. In particular in these simulation campaigns, network size was increased and both algorithms must find those multicast trees that satisfy bandwidth and delay constraints and optimize the total multicast tree cost. Both algorithms use the same network with the same load conditions. The considered network size was 10,20,40,80,100 nodes, each network has 30% of

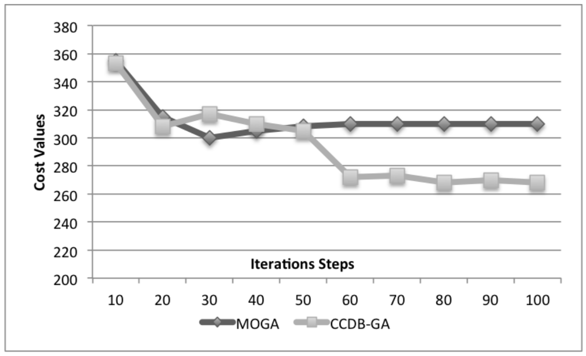

Fig. 3.18 CCDB-GA vs. MOGA - Cost trend comparison at iterations steps

destinations nodes. An execution time comparison between GA and SA algorithm has been made and results are shown in Figure3.19. The algorithm difference is not very accentuated when the network size is small, but with the increase of the network size, the difference is strongly marked and the SA spends more time to find the solution. This means that the HCDB-GA is more scalable than the SA algorithm proposed in the literature. This is due to how the algorithms explore the solution space. In fact, in order to achieve good solutions the SA requires more individuals to perform solution space investigation, therefore the SA consumes a lot of time to generate and evaluate solutions .

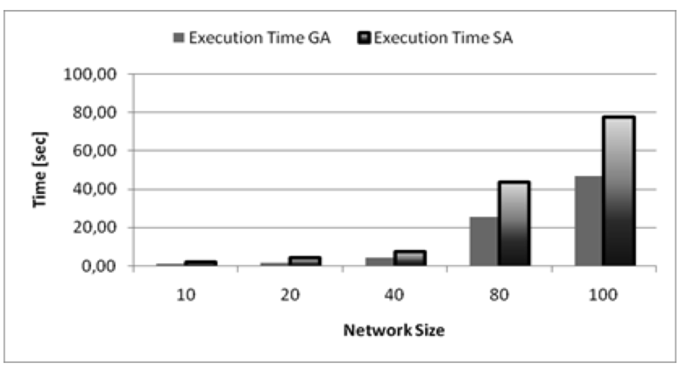

Fig. 3.19 Execution time comparison between GA and SA algorithm

In Figure3.20 the Average End-to-End delay is shown; as it is possible to observe the SA performs a better search for small network. On the other hand, when the network size increases, then the GA outperforms SA, finding a more feasible solution.

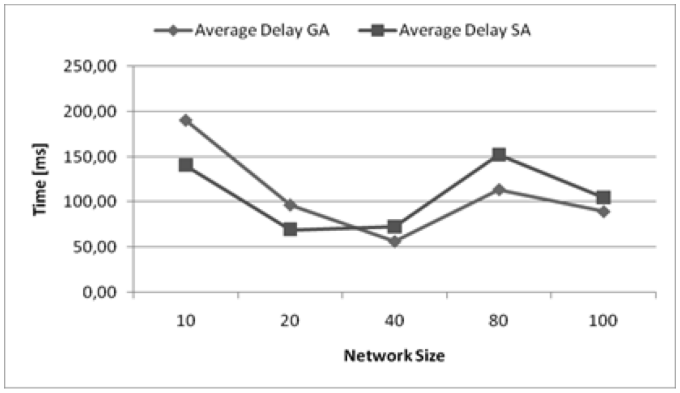

Fig. 3.20 Average End-to-End delay found by algorithms

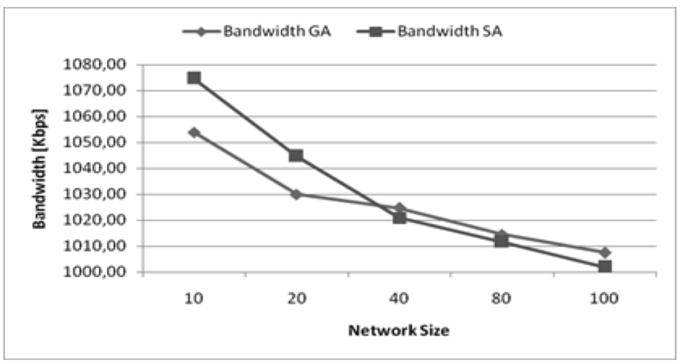

Fig. 3.21 Minimum Available bandwidth along the paths between source and destinations

In Figure3.21 the minimum available bandwidth along the path between the multicast source and the multicast destinations is depicted. This campaign shows found bandwidth vs. the multicast group destinations increasing. SA algorithm finds a better solution than the GA in terms of bandwidth but the GA finds a better solution in term of average end-to-end delay as it is possible to note in Figure 3.22

In order to confirm the previous affirmation the trend of the Max End-to-End delay is shown in Figure3.23 where the GA finds the same solution; while SA, in order to increase the available bandwidth, considers a solution that has a higher maximum end-to-end delay. This scenario shows how both algorithms find a trade-off that try to satisfy the imposed bounds. Therefore, it is important to tune the algorithms parameters in a right way avoiding the local optimum trap and to find solutions close to the optimal one.

These campaigns have shown that the SA can perform a better search than the GA in a small network context, but it is not scalable in comparison with the GA and, moreover, its solution quality is worse than the GA solutions.

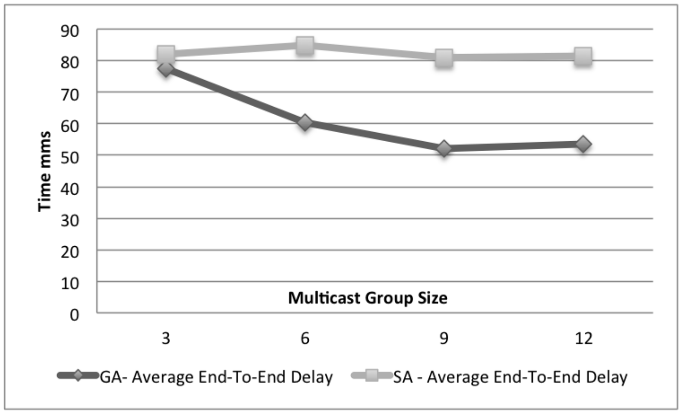

Fig. 3.22 Average End-to-End delay vs. Multicast group increasing

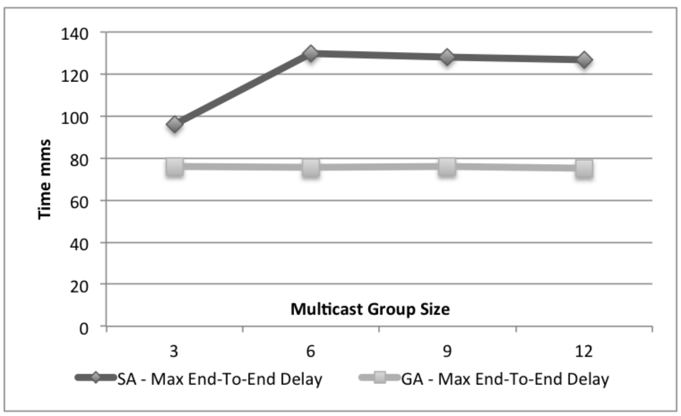

Fig. 3.23 Max End-to-End delay trend vs. Multicast group increasing

Another consideration must be taken into account, the GA algorithm can be tuned in order to perform a better search in a small network context changing its several configuration variables. This permits the HCDB-GA to be most easily configured into different contexts. SA algorithm is a good method to find multicast tree that satisfies several QoS constraints but more work are needed to increase its scalability and its solution quality. Moreover, it is also possible to increase temperature control mechanism so to move into the solution space in a better manner and reduce the convergence time.

In Figure 3.24 the distance (distance degree) between the optimal solution and found sub-optimal solutions using the genetic and the simulated annealing meta-heuristics is shown. In particular, how the meta-heuristics move into the solution space is shown in Figure 24. The GA has obtained better behaviors than the SA finding better solution close to the optimal solution. In fact, its distance degree is lesser than the distance degree of the SA. This

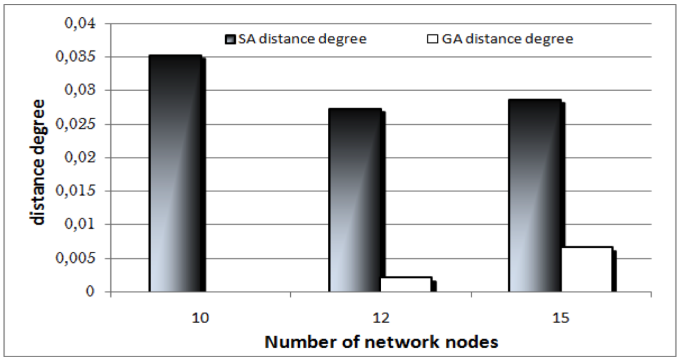

Fig. 3.24 Distance among the optimal solution and meta-heuristics found solution

means that the GA is more efficient than the SA and its solutions are also capable to respect the imposed QoS requirements. In these simulation campaigns end-to-end delay, bandwidth and multicast tree cost are taken into account and an overall optimization of the parameters has been effected . Both meta-heuristics have solutions found that respect the requirements.

3.5 Conclusions on Chapter 3

In this chapter QoS aware metaheuristics algorithm have been treated. In particular our attention has been focused on GA and SA algorithms. Their performances have been investigated in several network configurations and some comparisons between their performances have been made.

Initially, a description about the GA has been supplied and in particular its analytical formulation, where all steps of the GA has been illustrated. Moreover, each QoS constraints have been formulated and its contribution to the feasibility of the solution has been picked up.

Further the BG concept has been introduced in order to enhance the algorithm performances taking into account broadcast nature of the reference network. The BG allow us to find those solutions that permit to use a lesser number of nodes to spread information on the network. Therefore a multicast tree that has a higher level of density will be found. In other words the found solution will have these characteristics to use all those nodes of the network that permits to cover a higher number of nodes.

The SA has been introduced and the adaption of the algorithm to the multicast issues have been illustrated. Moreover, new temperature function that increases algorithm performances has been illustrated. In order to code and decode the data structure where the algorithm works a novel coding algorithm has been developed. The new temperature function allows to control temperature trends along all algorithm steps and permits to better investigate the solutions space. With the use of the uphill process it has been possible to avoid local optimum cage.

In the simulative campaigns the GA has been tested with different network loads and different scenarios have been illustrated. Moreover, in order to evaluate distance how far is the found solution from the optimal then a distance degree coefficient has been picked up. This coefficient has been also used to shown difference between GA and SA. In this simulative campaigns and with the used scenarios it is possible to note that GA and SA offer good performances, but actually the GA outperforms the SA in terms of quality of the found solution and in terms of execution time.

In order to find the right configuration between the weight coefficients of the hybrid algorithm some results have been depicted. As shown, if high density coverage levels and resources saving is what you are looking for, then the h1>h2 configuration allows to achieve these results, if optimal solution in terms of QoS is searched then more weight has to be given to the h2 coefficient, that spread solution around a higher number of nodes, but better solution in terms of QoS is found.

Chapter 4
QoS multicast protocol and algorithm

In this chapter the importance of the multicast protocol and the integration of the multicast protocol and multicast algorithm will be provided in order to further illustrate enhancement to the multicast sessions. A better integration between protocol and algorithm can enhance the overall performance of the system saving resource and allowing a higher number of users to be connected with the system. Moreover, better performance in terms of QoS can be observed by the end-user.

Multicast protocols are the manager of the multicast because they allow users to join the multicast session, manage the resource allocation and the overall load of the network. Several approaches have been proposed in these last years and each one has demonstrated to have good performances. In this work, a centralized protocol has been adopted due to the nature of the reference network. The proposed protocol permits to better manage the QoS requirements and allows a higher number of users to be served without wasting network resources. Better overhead has been obtained due to the enhanced management of the member join and member leave procedures other advantages have been obtained introducing QoS support to the protocol that can accept join request making some local tests to locally verify if the minimum QoS requirements can be satisfied by the network. This protocol has been called E-CBT, which is a QoS-driven protocol and it can consider additive and concave and multiplicative metrics. Moreover, the test platform was chosen to be a hybrid platform composed of one OBP satellite and an HAP mesh. In particular, the importance should be stressed of the constrained metrics choices such as end-to-end delay and minimum available bandwidth, which permit advantage to be taken of each single platform. The main contribution regards the introduction of this type of problem into a hybrid platform, where a multi-constrained QoS multicast is addressed. A detailed analysis on different metrics is done with the main objective of taking advantage of the multi-layer architecture. In particular, in order to obtain better performances by the heterogeneous architecture several algorithm-tuning campaigns were conducted; this has permitted to achieve a homogenous use of the network and a better resources management. As previously described, the particular characteristics of HAP and Satellite segment are the following:

- the lower bandwidth availability of the HAPs links respect the satellite downlink bandwidth
- higher propagation delay of the satellite respect the lower and greater footprint of the satellite rather than hap footprint;

In order to consider these characteristics a routing algorithm that exploits as better as possible network resources has to be applied. For these reasons the multicast protocol has been improved by the introduction of the GA.

Algorithm and Protocol integration will be further described. Moreover, protocol performances will be given to demonstrate the goodness of protocol respect the literature proposal.

4.1 Reference Scenario

As defined into previously chapters the reference network is composed of Satellite, HAPs mesh and terrestrial access point that works with a DVB-RCS like architecture. Network is shown in Figure 4.1

Each end-user has to be connected at the network trough a local access router, which is connected with the satellite and the HAP network. A source of a multicast group can log-in and a multicast group birth. Each multicast group has an unique multicast session ID that is available for all users that would like to connect at the network. In considered scenario some access routers are covered by both wireless connection but in other areas of the network only a satellite connection is available.

Moreover, multicast source could be also external to the network and the gateway allows multicast packets to flow inside the network. Each multicast session has to respect QoS constraints, in other words only log-in procedure that return positive results to QoS constraints test are allowed to be served by the multicast session. Those connection that not satisfies QoS requirements are not allowed and if some connections loss its capability to satisfy QoS requirements is dropped out.

4.2 Multicast Protocol

The CBT was chosen because it is a reliable and a scalable protocol, moreover, for the considered hierarchical and heterogeneous considered topology a core-based protocol can offer better performances than a source based approach. In the CBT protocol one element of a group (RCST, HAP or Satellite) is selected as the core for the group and then a tree is built to spam the traffic

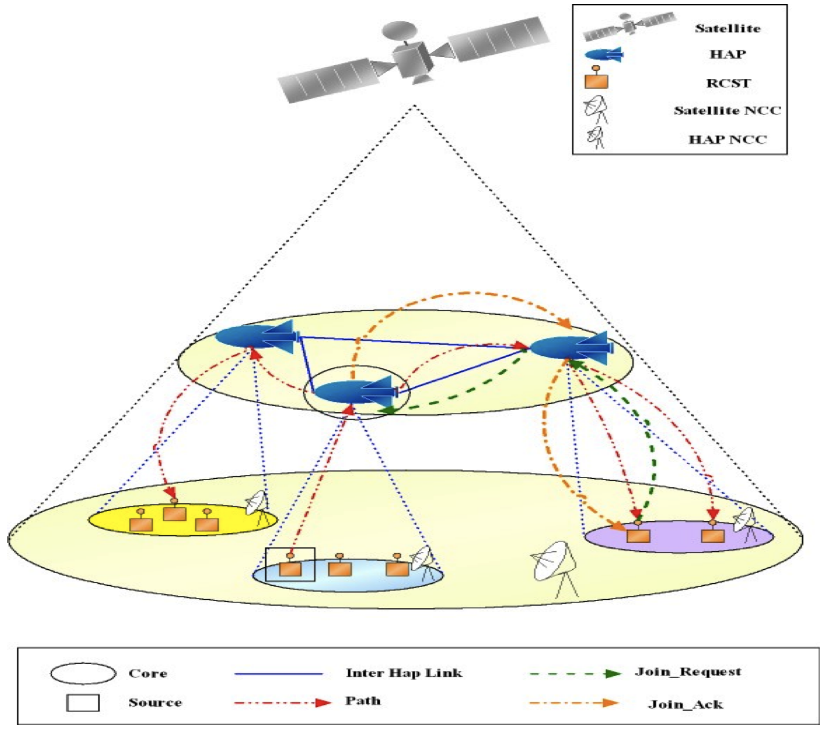

Fig. 4.1 Multicast Protocol Reference Network and Join Message scenario

that flows from the source to all group members. The birth of the multicast group is determined by the presence in the network of a source that, in order to communicate with other terminals, sends a particular message called Path (see Figure 4.1) that will reach all the network terminals.

4.2.1 Join Multicast session

A host, which wants to participate in the communication, expresses its interest in joining a group through an IGMP message called host membership report towards its local RCST (router).

Then, the RCST sends another message (message 2 in Figure4.2.1) called Join Request that travels in upstream hop-by-hop along the network until it arrives at the multicast group core.

This message changes the transient join state in the hop that it has travelled. If the transient join state is not "confirmed" with a join-acknowledgment message from the upstream interface the state is eventually timed out. When a router receives a join-acknowledgment (message 3 in Figure 4.2.1) it up-

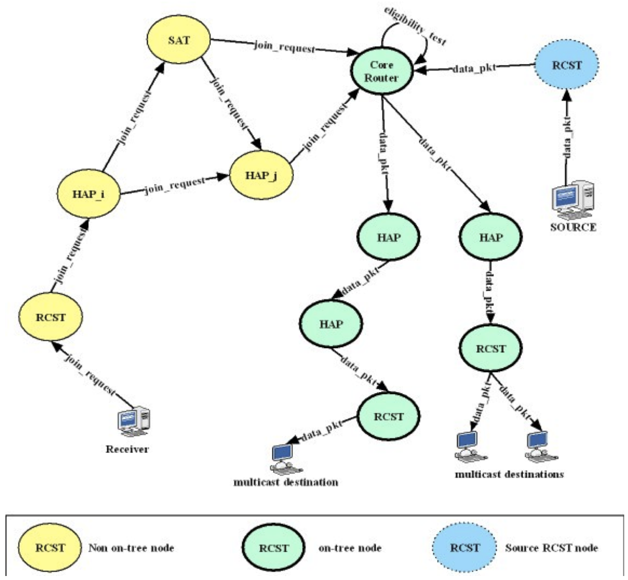

Fig. 4.2 Join Request Message

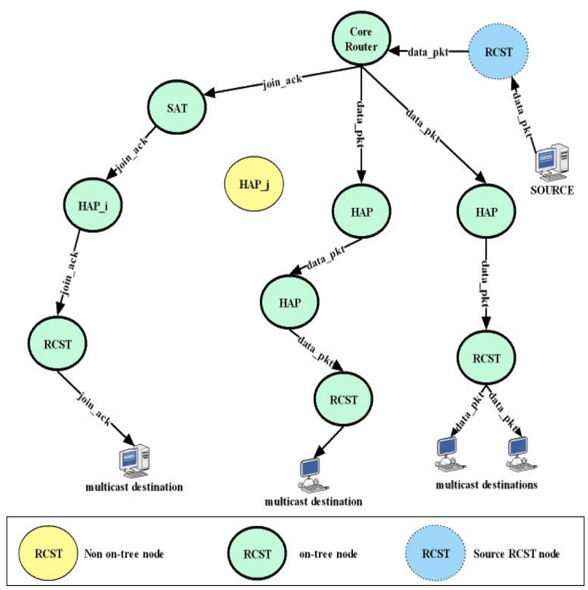

Fig. 4.3 Join ACK Message

dates its forwarding cache. This reflects the fact of being a new router in the multicast tree; Further it sends back the message until it reaches the router that first sent the join request.

When a join request message flows through the nodes it is possible to obtain two cases:

- if the node reached by the message is a non-on-tree node, this means that node is not known from the multicast group and for this reason the join request message transports information about the unknown network that will be stored into local structure of the message and these information is sent;
- In those cases when message reaches an on-tree node the topology storing process is stopped, and the message continues to flow through the multicast tree until it reaches the core router.

When all procedures of the join request are ended, the scenario shown in Figure 4.2.1 is obtained. In order to build new branches, which permit multicast destination to be reached, protocol is helped by the multicast algorithm that taking into account network topology and multicast tree communication requirements search for a path that satisfies QoS requirements allowing destinations to receive multicast service. It builds a feasible root that permits data flow to be sent among on-tree nodes.

4.2.2 Multicast Tree Maintenance

Tree maintenance is achieved in this way: each router sends a CBT keep alive message periodically towards its tree parent router. The receipt of the message over a valid child interface prompts the sending of a response message called echo reply that carries a list of groups for which the corresponding interface is a child interface. If some responses do not come back once the timeout is expired , then, router sends a message called quit-notification on the upstream interface and flushes all of its downstream branches by sending flush-tree messages. This mechanism allows the host to individually re-join if necessary.

4.2.3 Member Leave

When a host decides to leave the multicast session, it sends another kind of message, called member-leave, towards its parent router. The parent router checks if some on-tree router is connected on its downstream interface; it sends a quit-notification message to its parent router and if there are not other routers connected with it, then it deletes its corresponding forwarding cache. Finally, during the data transmission, packets flow from source towards multicast destinations. The source sends packets along the path that carries packets toward the core router. Data packets are sent down towards all multicast tree branches until all the group members receive data. The last phase of the protocol is represented by the End Multicast Session (EMS).

4.2.4 End Multicast Session

This message is sent by the source over the network when its work is finished. Reserved resources must be released when an EMS is sent. If a generic node receives the EMS it empties the buffer and only when the buffer is empty it sends the EMS through its downlink interfaces. In order to reallocate its resource the router must wait for a response which indicates that all work has been made by its downlink interfaces. The EMS flow is shown in Figure 4.4 and in Figure 4.5. In Figure 4.5, the further answer phase has been depicted, in order to better understand the figure it is important to define the representation of the link weights :

- The first number indicates the temporal order of the messages;
- The second number indicates the destination router of the message;

In particular, when an EMS reaches the destination hosts of the considered multicast sessions, they send back an echo message towards its RCSTs. The RCST wait until all hosts connected send back an echo message; then, it can send back, towards its father, the EMS echo messages. Once a router receives all the EMS echo messages, then it can prune the link towards its child interfaces, which are involved in the multicast sessions; moreover, it can release those resources previously utilized in order to make them available for next multicast sessions.

4.2.5 QoS Aware multicast protocol

In this section the QoS aware protocol is depicted. this extension allow multicast protocol to consider QoS[47] making some local test when a member join is sent along the network. This allow us to filter those request that cannot be satisfied locally. In this way a less number of member join travels on the network reducing overhead. In this work several QoS metrics have been considered, moreover, all join process has been enhanced in order to consider more path and then thanks to the multicast algorithm called by the router the chosen path will be the better one and not only the first that come to the core router.

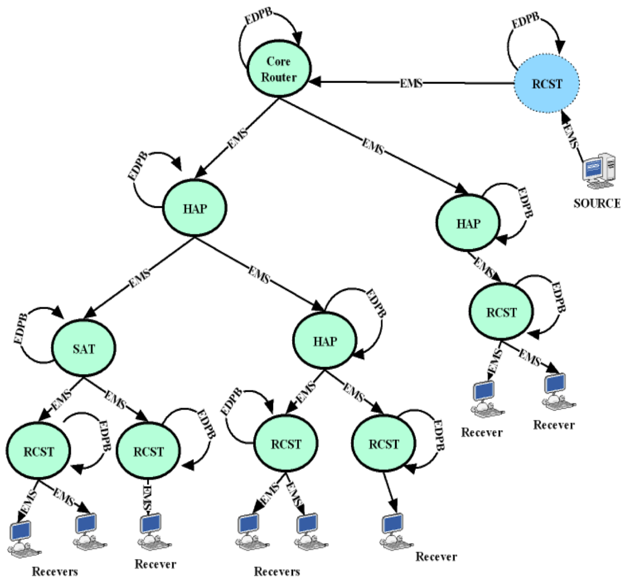

Fig. 4.4 EMS

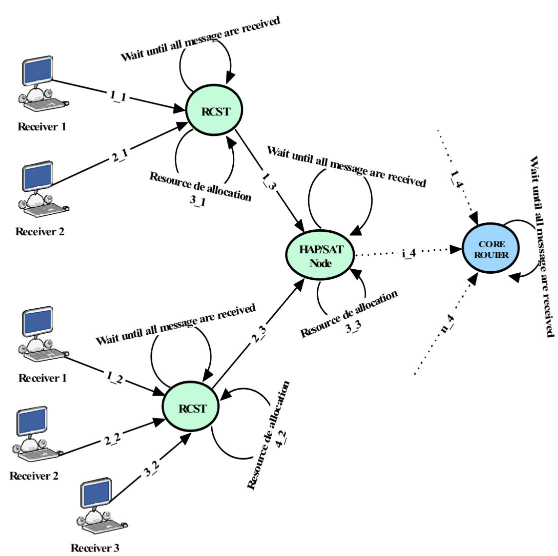

Fig. 4.5 Terminals Answer to EMS

The join request messages, also contains information about QoS metrics such as delay, bandwidth and so on. When a join-request message reaches the core or an on-tree router, the core/on-tree router performs a set of eligibility tests. Preferably, the eligibility test should be conducted locally, but this is not sufficient to admit a request of join-request. The join request message then flows through the network until it arrives at the core router. Therefore, the last test is performed and the host can be admitted to participate in the multicast session, only if the eligibility test is passed, in this case the new member is accepted and a join-acknowledgment message is sent. New version of protocol, which has been proposed at this point collects several message of join and only after that a collection timeout is expired the message is considered valid and a path computation is performed by the core router when the join message reach the core.

In the member leaving phases the state keeps at the other on-tree routers could be updated, therefore, the on-tree router performs procedures that notify the other on-tree routers to update their states. When a member leave message arrives to an on-tree router, it makes a check on its downlink interfaces, if no more interfaces of the multicast group are present; the resources allocated to the multicast group are released. To satisfy the end-to-end delay bound, each on-tree router keeps the following states for each downstream interface. In the following the CBT extension is presented, in this case an additive QoS metric is considered. In further the downstream interface is used, with this term we refer to the interface that are used to distribute network data flow from source router to destinations.

$[\nabla_{u,*}^{max}]_i$ is the maximum delay among the path between the router {u} and all downstream interfaces that can be reached using the output interface {i}

$\left[\nabla_{*,u}^{max}\right]_i$ is the maximum delay among the path between all destinations that are reached by the interface i to the node {u}

For each node a state is maintained and indicates the maximum delay for all downstream interfaces. Suppose that the node {u} has 5 downstream interfaces therefore the on-tree node delay state is given by the eq. 4.1

$$\left[\nabla_{u,*}^{max}\right] = max\{\left[\nabla_{u,*}^{max}\right]_i : i = [1..5]\} \tag{4.1}$$

$$\left[\nabla_{*,u}^{max}\right] = max\{\left[\nabla_{*,u}^{max}\right]_i : i = [1..5]\} \tag{4.2}$$

Moreover, the maximum outgoing/incoming delay of a generic router {u} is supplied by the eq. 4.3, eq.4.4.

$$\left[\nabla_{u,*}^{max}\right]_{i/\{l\}} = max_{i \in I/\{l\}} \left[\nabla_{u,*}^{max}\right]_i \tag{4.3}$$

$$\left[\nabla_{*,u}^{max}\right]_{i/\{l\}} = max_{i \in I/\{l\}} \left[\nabla_{*,u}^{max}\right]_i \tag{4.4}$$

In the eq.4.3, eq.4.4 the I is the set of all downstream interfaces of the on-tree router {u}, and l is the interface on which a member join/leave reach the on-tree node {u}.

Ts(u) indicates the sub-tree rooted at router {u}. Each on-tree router only keeps the state information for Ts(u). The reason for keeping per-downstream-interface (instead of per-node) state will be clearer when the member join/leave procedure is discussed. When a join request message from a joining router {v} arrives at an on-tree router {u} on interface i, on tree router {u} checks the

$$\left[\nabla^{max}_{*,v}\right] = \delta_{u,v} + \left[\nabla^{max}_{*,u}\right]_{I/\{i\}} \leq \phi \tag{4.5}$$

In the eq.4.5the terms $\delta_{u,v}$is picked up with the join request message and it is updated to each step of the trip between the node {v} and the node {u}. While ϕ is an upper bound that the RCST sent on join request message.

Only if all controls, which flow along the path from receiver to core router, are passed then join request arrives at the core that will send back a message called join ACK. When this message arrives at a non-on-tree router the resource can be allocated and a new branch is added to the multicast tree. When an element receives a join ack message, it updates its forwarding cache to reflect the fact that it now becomes an on-tree element. Otherwise, if the QoS test is not passed then the node sends back a message that advises the previous node that the minimum QoS requirements are not satisfied.

The E-CBT allow us to also consider QoS constraints such as the bandwidth, in order to supplied bandwidth support the eq.4.6 has to been verified, if not the join is suddenly rejected and the a rejection-replay message is sent towards the join node {v} using the downstream interface i along the join messages come.

$$b_{u,v} \geq \mu \tag{4.6}$$

In the eq. 4.6 the μ is the lower bound related to the bandwidth that has to be available along the path between nodes {u} and {v}.

When a member router v leaves a multicast tree it sends a quit-notification message to its parent router u. If router u does not have any other local members or downstream on-tree routers, it sends a quit-notification message to its parent router w and deletes the corresponding forwarding cache. Otherwise, router u deletes the interface on which the quit-notification message arrives from the forwarding cache.

4.2.6 Core Election

In a core based protocol the election of the core router is a key factor to achieve good performances. In order to make core choice the following marker has been computed for each node of the network. This marker is used to perform the core router choice [33]. When high dynamic network are considered the core router election is made several times monitoring tree degradation. Let us to recall some network model formulations that it is just given in previous chapter. Let V be the set of nodes, E is the the set of the edges that connect the nodes in V, and G(V,E) is the unoriented graph that represents the network topology. In this scenario, consider nodes {u} and {v} where $u \in V$ and $v \in V$ then the sum along the shortest path between the two nodes is indicated as r(u,v). Therefore the average cost of a generic node $c \in V$ is given by the eq. 4.7

$$cost(c) = \frac{1}{|V|} * \sum_{x \in V/\{c\}} r(c, x) \tag{4.7}$$

The core election principle is based on the minimum average cost. Hence, the core router shall be the node that has the minimum average cost. This is summary in the

$$cr = c \in V : \forall c, x \in V, c \neq x \Rightarrow cost(c) < cost(x) \tag{4.8}$$

4.3 Multicast Protocol and Multicast Algorithm integration

Algorithms and Protocols work together in order to achieve the best system performances. In particular, the multicast protocol triggers algorithm when a new route is needed in order to reach a host. In the proposed work, the Core Router starts the algorithm execution when it receives a member join. In order to better understand the algorithm and protocol interaction an example is presented. This example considers a generic network composed of some routers and some hosts. In particular a session is just initialized and a source transmits a service (data flow) on the network.

This service is received by some hosts in the network. Let us suppose that a host wants to connect itself with a router that is in the network; moreover, let us suppose that this router is not an on-tree router, therefore, the router sends on the network with the flooding technique a join-host message. This message travels on the network until it reaches an on-tree router. The on-tree router sends the message over the multicast tree. This procedure is executed until the message reaches the Core Router. If all tests are passed then the Core Router admits the host and this last one can receive the data flow. Moreover, the Core Router stores more than one join message, because it evaluates which of them represents a more feasible path. Once the Core Router chooses the best join message, it sends back the acknowledgment to the join request. If there are not routes that can connect the host, the multicast algorithm

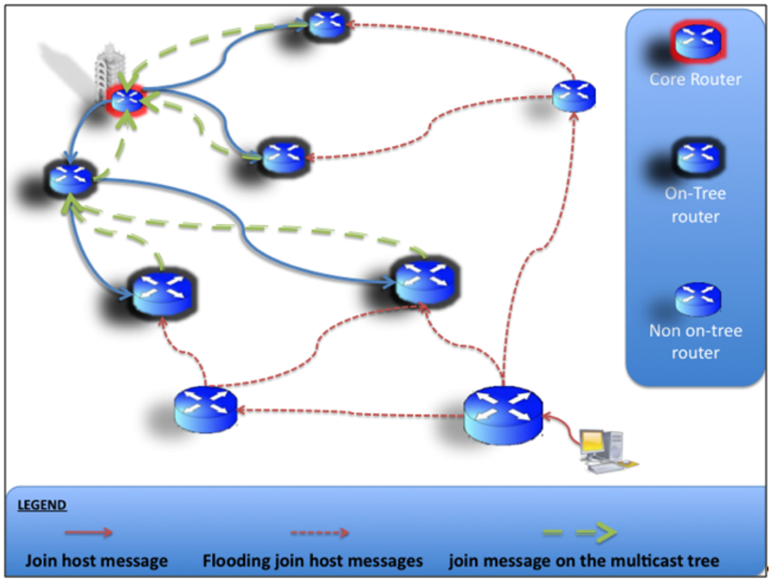

Fig. 4.6 E-CBT example working scenario

is executed in order to find a feasible route that can connect the host to the multicast tree. The Core Router also uses the join request message to collect information on the unknown network. In fact, each router can store information which are coming with the join request message, in this way a sub-map of the network is stored.

4.3.1 CBT with QoS aware support

In this section a briefly description of CBT that support the QoS is given, moreover at the end also the weakness of the protocol approach is given. Supposing that a multicast session is working and it is active on the network, then we suppose that at unspecified instant of time a node expresses its will to join into the multicast group, the in this case the protocol behavior is shown in the Figure4.7.

The host sends a join host message to its local router. When a router receives a message it stores all the information about the unknown topology or about that topology portion that is updated. In this way, the network topology is updated. Node N is the current node reached by the join message. It is interesting to observe the three different hierarchical levels of the network node. The most important is the core router, which has several tasks, but in the join phase it has the task of deciding whether a host can or cannot join into the multicast group. This flow chart shows a CBT multicast protocol

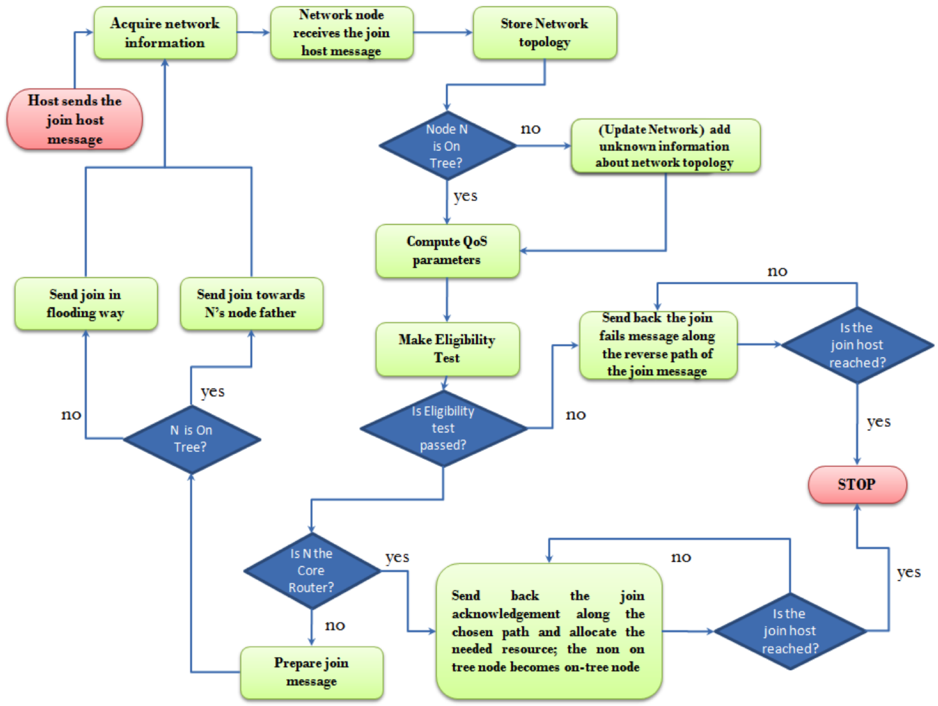

Fig. 4.7 QoS aware CBT

execution with a greedy algorithm. Even in this approach, which has also been proposed in the literature, the protocol executes a greedy multicast algorithm in order to find a feasible route capable of reaching the host that requested a join. In this way, the protocol cannot consider all the possibilities that the network can offer, and, in particular, the solution found could be far from the optimal one. In particular, this is not good when several constraints should be respected. Moreover, the eligibility test helps us to ensure that the path reached at the core router can satisfy a QoS parameter, but what happens if the network rapidly changes its condition? Through this approach it is very hard ever to assure the feasibility of the solution found. Furthermore, we are not sure that the non-on-tree routers can offer a feasible way to serve the host that requested to join in the multicast group. Another weakness is that the core router does not consider all the possible ways of reaching the host and it chooses the first path that is received and that has passed the final eligibility test. Therefore, the chosen path could not be the best one.

4.3.2 E-CBT QoS Aware Multicast Protocol

In this section the E-CBT protocol with the QoS support and new GA integration is depicted to show the protocol and algorithm integration. In order to better explain the multicast protocol the Figure4.8 depicts the protocol steps.

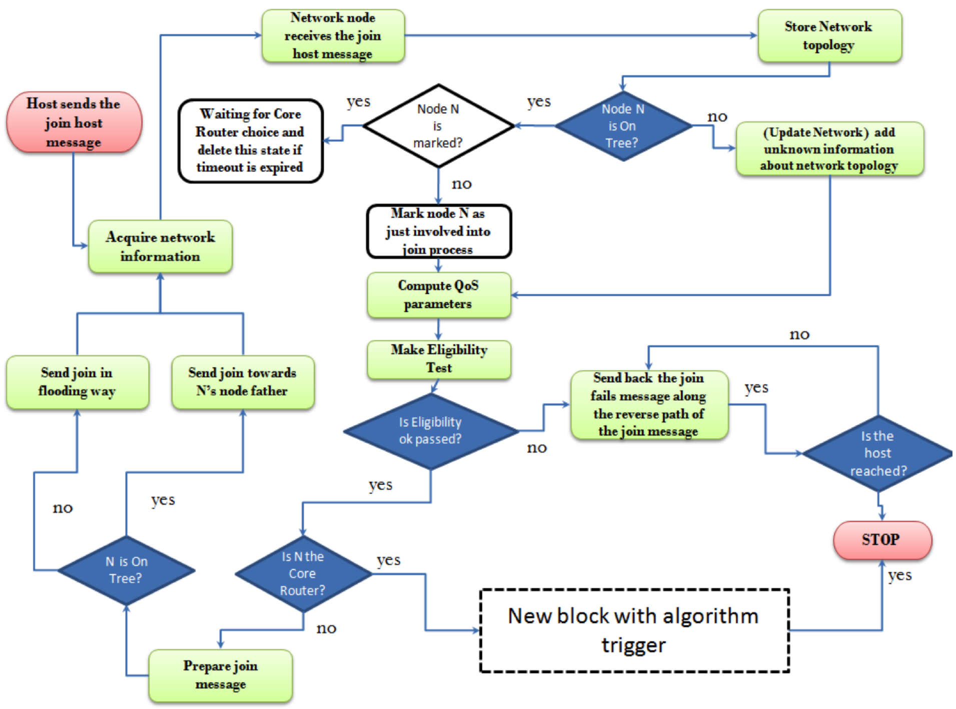

Fig. 4.8 E-CBT main Loop

This flow chart shows our QoS aware multicast protocol, which also outperforms the previous greedy algorithm, in fact it can use algorithms such as GA and SA algorithm, which permit to consider several QoS requirements such as end-to-end delay, bandwidth and so on. It is easy to note how this flow chart is different from the previous one. In particular, a first block was added in order to consider more join messages and taking advantage of the flooding technique; but also to reduce protocol packets, a filter on the on-tree router is used. This filter sets a particular state into the on-tree routers that stores information about the host that has generated the join request and about the travelled network, this process is called node mark. When a non on-tree node is reached by a member join request the node is marked if it is not just enveloped into a join membership process related to the same multicast group. This state is then deleted if the on-tree router is chosen to reach the host or when timeout expires. The eligibility test is executed locally and if passed the message is sent along the incoming interface of the node. This process is repeated until a on-tree node is reached, in this case the member join is sent along the tree branches until the core router is reached. When message reaches the core router, the core performs the multicast algorithm in order to find the better path to reach the host that has ask the join request.

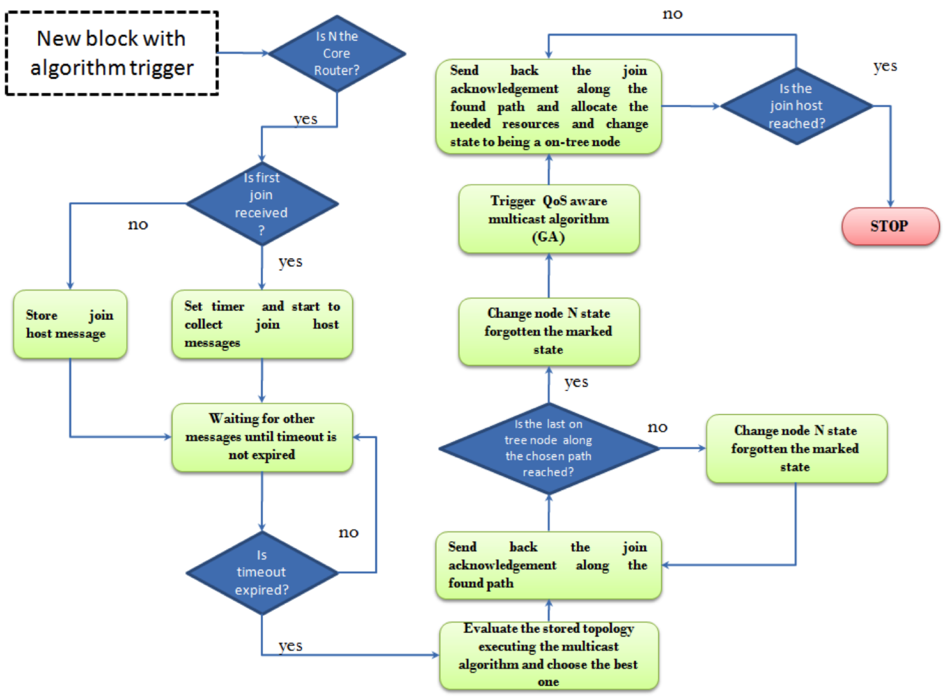

Fig. 4.9 E-CBT Algorithm Trigger

Furthermore, a more complex strategy is utilized to choose the path to reach the multicast destination. In order to better explore the solution space the core router chooses the best path between the source and the destination ("join host" into flow chart). Clearly, branches and nodes, which are known thanks to the join messages that the core router has received, are considered. In this way, the core router makes a choice, taking into account several possible paths. When a membership join reaches the core router, it starts to collect messages of other join that may come from other paths. When the collect timeout is expired then then the multicast algorithm is triggered and a path is found. Therefore, the join host acknowledgement is sent along the path chosen by the core router, until it reaches the last on-tree router. The latter performs an algorithm execution on that network topology that the router has collected with other join messages that it has received thanks to the flooding technique. Once the algorithm ends it return a subtree routed into last on-tree node. Acknowledgment message is sent towards the multicast destination and all needed resources are allocated, in this way the data-flow start to floods towards the multicast destination. Therefore, it is clear that this solution is more feasible than the previous approach and it can assure respect of QoS requirements. Moreover, different kinds of QoS metrics can be considered for the multicast routing, this permits a wide class of application to be considered and allows consideration of finding a good trade-off between QoS requirements and a more complex application that requires more than one QoS criteria satisfaction.

4.4 Simulation campaigns

The protocol performances are shown in this section. In particular, the protocol behavior into a heterogeneous wireless topology was investigated. In order to carry out results a Discrete Event Simulator has been used that implements protocols and algorithm over the multilayer hierarchical network[40]. Moreover, the protocol can consider the QoS requirements more efficiently using the GA algorithm. These simulation campaigns have been carried out considering the configuration parameters given in table I and table II. Furthermore, the simulation takes into account the number of sources and destinations terminals variation covered by each HAP into the considered system.

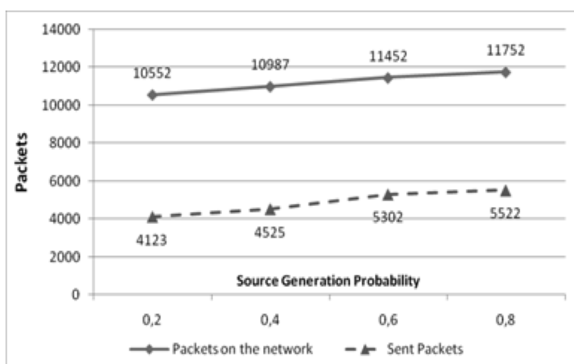

Fig. 4.10 Packets number vs. source generation probability

Figure4.10 shows how a greater sources number, owing to the higher source generation probability, carries out an increase of packets number. The difference between the curve slopes shows how the multicast algorithm acts on the packets that travel in the network. In fact, an efficient multicast tree permits the imposed bounds to be respected over sensible QoS parameters, but also permits precious resources such as available bandwidth to be saved over the multicast tree branches. It is possible to note how an increase of generated packets does not augment the packets that travel in the network. This means that the multicast paradigm permits a lower number of packets to be sent.

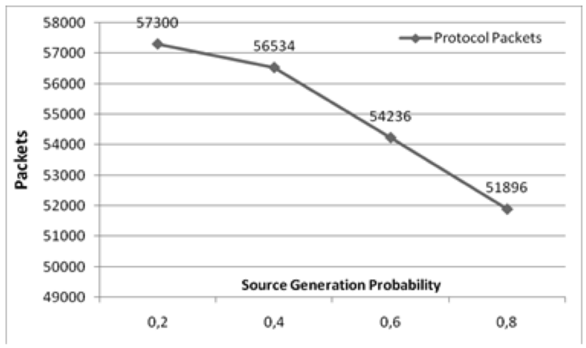

Fig. 4.11 Protocols packets number vs. source generation probability

Figure4.11 shows the protocol packets number versus source generation probability. It is possible to observe how a greater sources number implies a lower number of sent protocol packets. This is possible because an increase of source terminals limits the birth of receiver terminals, therefore a lower number of member join or member leave messages are generated in the network. This means that higher is the number of multicast sessions active in the network, lesser is the number of admitted receiver into the network due to QoS constraints, which have to be respected. In fact a higher number of multicast sessions means that in the network more resources are allocated due to the spreading of the data flows that is coming from several sources that belong to several multicast group. Therefore, lower bandwidth is available for new connections.

Figure4.12 shows the return link utilization, it increases because a greater data packet forwarding is sent by a wider number of contemporary sources that utilize a higher bandwidth. In addition, RCST-SAT is lesser utilized than the RCST-HAP link because the HAPs guarantee a lower propagation delay than the satellite, whereas the satellite uplink is utilized in order to connect those HAPs that are distant from each other and when no real time applications (with higher tolerated delay) are considered.

Figure4.13 shows the forward link utilization of HAP/Satellite towards the RCST. The sources increase implies an augment of the HAP-RCST link utilization owing to a greater load, which must be distributed to the receiver terminals. Moreover, it is possible to note an increase of the inter-HAP links utilization that indicates that in this kind of configuration the information

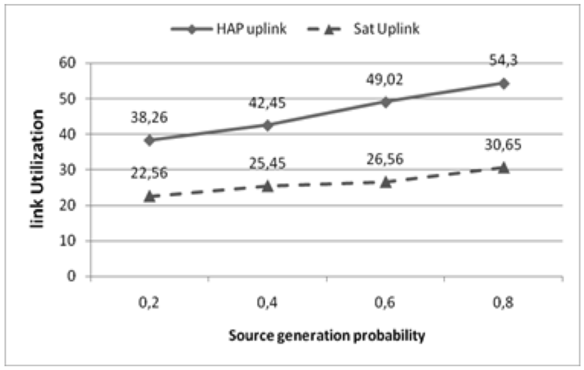

Fig. 4.12 RCST link average utilization vs. source generation probability

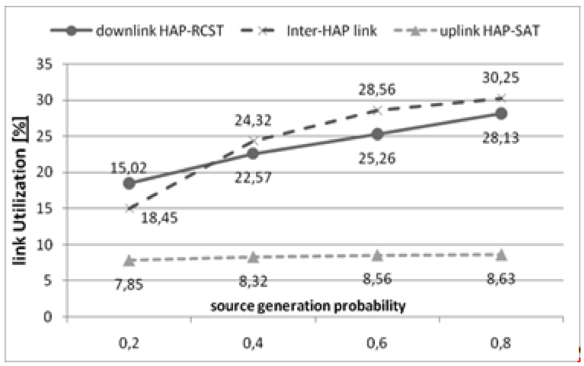

Fig. 4.13 HAP link average utilization vs. source generation probability

exchanged between HAPs is favorite in order to respect an end-to-end delay bound. Finally, the increase of HAP-Satellite link utilization is due to congestion problems of HAP-HAP link that could happen when the HAP links are too much used.

In the following figures the requested bandwidth is changed, therefore link utilization vs. requested bandwidth per each multicast session results are carried out. The request bandwidth for multicast sessions are 300, 548, 800 and 1024 Kbps respectively. In the Figure 4.14 . Moreover, it is possible to note that links utilization goes towards a saturation stability where new connections are not allowed due to QoS limits. Therefore, since the INTER-HAP links are loaded the algorithm switch transmission on the HAP-SAT links, which previously was used only to connect those HAPs that belong to different HAP meshes. Instead, considering the new load condition, algorithm search for other sub-optimal solutions that can respect QoS bounds but they are not the better solutions in terms of round-trip delay. This allow us to achieve a higher degree of fairness among nodes and links load and a feasible solution that belongs to the solution space is also find.

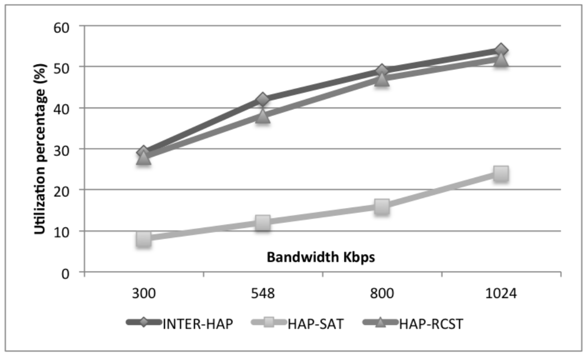

Fig. 4.14 Average HAP layer Links Utilization

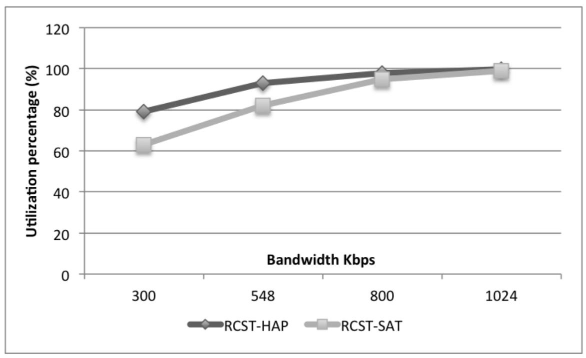

Fig. 4.15 Average RCST layer Links Utilization

In figure 4.15 is depicted the links utilization that connect the RCSTs to the HAP and Satellite layers. It is possible to note that the fork between the links utilization is reduced when a higher amount of bandwidth is requested. This happen because the links goes towards a saturation and the algorithm adapt routing in order to guarantee a certain level of fairness on links load and to allow as higher as possible number of connections. The growth of the requested bandwidth may depend of the amount of bandwidth that each source that connects to the network require to initialize the multicast session.

In the Figure 4.16 the mean hop counter related to the multicast algorithm modality configuration has been depicted. In particular as illustrated into chapter three, the multicast algorithm has been designed to perform three different optimization configurations. The first one is the Cost-Bandwidth optimization where only bandwidth is taken as QoS constraints and the cost is a metrics to be optimized but. The second case is represented by the Cost-Delay configuration in which only the End-To-End delay is considered as QoS constraints. In the full optimization configuration are considered both QoS metrics and the cost is an index that has to be optimized. As is possible to

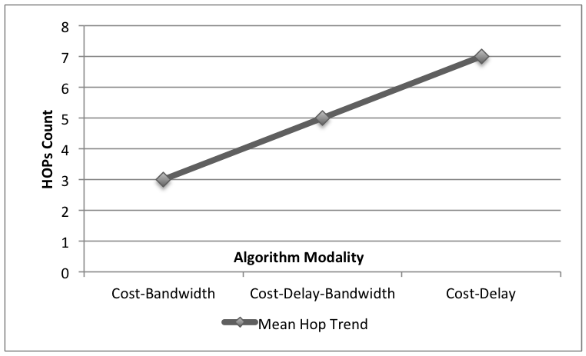

Fig. 4.16 Average RCST layer Links Utilization

note in the Cost-Bandwidth configuration we have obtained a lesser number of mean hop because the satellite link is much more utilized and thanks to its great footprint it is possible to cover a wide area. In the opposite case, when the Cost-Delay is considered the mean Hops is greater than the previously because in order to guarantee a service coverage in all the network a higher number of HAPs are evolved into multicast sessions. The HAPs, in fact, have a lower round-trip-delay than the satellite, therefore they are favorite to make connections between nodes. In the last configuration where all QoS parameters have to be respected a intermediate value between the previous cases is obtained. This means that both kind of links that belong to the HAP layer and Satellite Layer are used, but algorithm find a good trade-off to guarantee performances and a higher level of QoS.

4.5 Conclusion on chapter 4

In this chapter a description of the protocols and their integration with the multi-constraints multicast algorithm has been given. In particular, a description about the CBT protocol has given to introduce the enhancements that we have proposed in this work. The CBT protocol as known is a multicast protocol that belongs to the core based protocols family, but initially it has been designed to do not supply QoS support. In the first phase, a QoS support has been added to the protocol using some local tests to verify if the QoS requirements are satisfied locally. If these test are passed then the join request is sent upwards the network. In this case a protocol overhead is reduced because those requests that does not satisfy the QoS requirements is stopped and no more actions have conducted about them. Its important to recall that the local test is performed to each nodes that the join message meet. When the join request reaches the core router also a global test is performed to verify QoS requirements. At this point the multicast algorithm is triggered to find the better path that allow end-user to receive data. When the path is found then the resource are reserved and those nodes, which are not marked as an on-tree node being to be a on-tree node. As carried out from simulative campaigns the multicast protocol with the algorithm support achieve good performances and optimal solutions are found to distribute network data-flow. Moreover, the protocol overhead has been reduced allowing more resources to be allocated for data flow management. In adding the multicast algorithm has permitted to save cpu cycles that in this way can manage more sessions avoiding cpu overload.

Conclusions

In this Phd Thesis, the QoS multicast over a multilayer hierarchical network has been discussed. Main aspect of the multicast have been faced, and in particular our attention have been focused on QoS multi constraints protocols and algorithms.

In first chapter an overview on the reference network has been given. The satellite network is composed of an OBP satellite with DVB-RCS architecture that permits to exploit both uplink and downlink to send data. Moreover, high bandwidth is guaranteed by the satellite links, and the multi protocol encapsulation permits to send TCP/IP packets on the network. To increase network performances and in particular to reduce round trip delay has been introduced a HAPs mesh segment, which includes several HAPs that can communicate with satellite and with on-earth terminals, moreover an inter-hap communications is also provided exploiting inter-hap links. This permits to cover a wide area with broadband services. Moreover, HAPs guarantee a good footprint and allow several users to be served with a wide range of wireless services. One of the main advantage of this network is to cover a wide area and allow operator to install or move network in a easy manner. In fact, HAP can be reallocated or installed faster making possible connection and allowing emergency services widely and faster.

The advantage of the multilayer and hierarchical network has been considered into multicast QoS problem formulation that has been faced into the second chapter. In this chapter are also discussed the state of art of the Protocols and Algorithms and in particular the complexity of the problem has been treated. In fact, the multi-constraints QoS multicast is belongs to the NP-Complete class of problem because it is a STP problem that cannot be reduced in terms of complexity. Then the problem has been proposed in analytical form and the base for the analysis made in third chapter is supplied.

In the third chapter the multi-constraints QoS issues has been discussed and some meta-heuristics has been presented. In particular, the Genetic Algorithm and the Simulated Annealing algorithms have been addressed. The complexity of the problem has drive us towards meta-heuristics algorithms that offer several advantages. First of all this is a NP-Complete problem and it is known in literature as STP as aforementioned said; hence is not possible to solve this class of problem using polynomial algorithms like those used in combinatorial problem to find an optimum solution, because resources and time limits have to be considered.

The heuristic and the meta-heuristics allow us to work on complex problem using a limited amount of resources founding an admissible solutions into a limit number of steps.

The GA permits to investigate into solution space searching for an admissible solution that is as close as possible at the optimum one. Several issues has been faced into this process and several tuning campaigns have been conducted to find the right parameters to applied. Newest coding/decoding procedures and newest Fitness function assignments have been proposed to increase algorithm performances. Moreover, considering network architecture as main key, a broadcast gain concept has been introduced into the algorithm and better performances have been achieved.

The SA algorithm has been investigated and increased in its performance. First of all has been proposed a problem formulation and the algorithm has been designed for the multi-constraints QoS multicast aware problem, in order to compare two meta-heuristics same QoS constraints have been considered. The SA takes advantages from the metallic characteristics and in particular from the kinetic energy of the metal's atoms when it is heated, in fact higher is the temperature and more energy have the atoms, in our field a higher temperature means a higher probability of solution changing. If temperature is rapidly decreased an unordered structure is formed and this means that a admissible solution might be found but this does not guarantee that we have widely moved into solution space. Instead, if the temperature decrease too slowly this means that should be possible to not converge towards a solution. For this reason a new temperature function has been proposed and good results have been carried out. Moreover, in the SA approach have been proposed a new coding algorithm, that permits to reduce coding complexity and a new algorithm that takes into account history of the last 5 iterations has been introduced into temperature updating functions.

In the forth chapter the QoS multicast protocol and its integration with multicast QoS algorithm has been addressed. QoS protocol has the main goal to manage the multicast sessions and allow packets to flow on the network. Moreover, the multicast tree management and its maintaining is also a task of the multicast protocol. Multi-constraints QoS multicast can allow system to manage a higher number of users connected at the multicast sessions. Moreover, with a better resources management the end-users can take advantage of network due to the increased quality of the received services. The integration of the algorithm with the protocol has permitted to increase the quality of the multicast sessions. In the protocol has been added the management of the QoS with the introduction of local test and global test, moreover, tree rearrangement is also been considered. At the end to provide a better core selection has been introduced a function that allow us to find a node that could be a optimum core for the multicast sessions.

At the end several simulation campaigns have been carried out and protocol and algorithm goodness have been proof. The E-CBT has permitted to reduce overall overhead and achieve a better use of links. Moreover, all QoS constraints have been respected and a higher number of users have been admitted to multicast sessions. Saving bandwidth and time resources more services should be supplied by the network without wast network performance or overall QoS of the system.

References

1. De Rango F., Tropea M., Santamaria A.F, Marano S., “Multicast QoS Core-Based Tree Routing Protocol and Genetic Algorithm Over an HAP-Satellite Architecture,” in IEEE Transaction on Vehicular Technology, Vol.58, Issue 8, 2009, pp.4447 – 4461
2. ETSI EN 301 790 V1.4.1 (2005-09) : ”Digital Video Broadcasting (DVB); Interaction channel for satellite distribution systems”, ETSI 2009.
3. F.De Rango, A.F.Santamaria, M.Tropea, S.Marano, "Meta-heuristics methods for a NP-Complete networking problem," 66th IEEE Vehicular Technology Conference (VTC Fall 2008), Calgary, Alberta, Canada, 21-24 Sept. 2008
4. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, “An Enhanced QoS CBT Multicast Routing Protocol based on Genetic Algorithm in a Hybrid HAP-Satellite System,” Computer Communication Journal (Elsevier), in December 2007.
5. Huang Lin; Zhang Yu-Lin; Ren Yong-Hong, “Two multi-constrained multicast QoS routing algorithms”, Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, 2007. SNPD 2007. Eighth ACIS International Conference on Volume 3, July 30 2007-Aug. 1 2007 Page(s):495 – 500.
6. F. De Rango, M.Tropea, S.Marano, “Integrated Services on High Altitude Platform: Receiver Driven Smart Selection of HAP-Geo SatelliteWireless Access Segment and Performance Evaluation,” in Int. Journ. Of Wireless Information Networks, 2006.
7. A. Morello and V. Mignone, “DVB-S2: The Second Generation Standard for Satellite Broad-band Services”, Proceeding of IEEE VOL.94, NO. 1, JANUARY 2006.
8. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "A QoS Multicast Genetic Algorithm in a Hybrid HAP/DVB-RCS Satellite Platform," 13rd International Conference on Telecommunications (ICT 2006), Madeira Island, Portugal, May 9-12, 2006.
9. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "QoS Core Based Tree Multicast Routing based on Genetic Algorithm in a Hybrid HAP-Satellite Architecture," Int. Symposium on Performance Evaluation of Comp. and Telecomm. Systems (SPECTS’06), July 31 – Aug.2, 2006.
10. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "QoS Multicast over Hybrid HAP-Satellite Networks," 12th Ka and Broadband Communications Conference, Naples, Italy,
11. Kun Zhang; Fengyu Liu; Yi Zhong, “An efficient multicast routing algorithm based on simulated annealing for multimedia communications”, IEEE International Conference on Systems, Man and Cybernetics, Vol.1, Oct. 2005, pp. 369- 374.

12. E. Cianca, R. Prasad, M. De Sanctis, A. De Luise, M. Antonini, D. Teotino, M. Ruggeri, “Integrated Satellite-HAP Systems, IEEE Radio Communications, December 2005.
13. S. Karapantazis, F.N. Pavlidou, “Broadband Communications Via High-Altitude Platforms: A Survey”, IEEE Communications Surveys & Tutorials, 2005
14. ETSI, “User Guidelines for the Second Generation Systems for Broadcasting, Interactive Services, News Gathering and Other Broadband Satellite Applications,” TR 102 376, Feb. 2005; http://www.etsi.org.
15. A. Roy, S. K. Das “QM2RP: A QoS-Based Mobile Multicast Routing Protocol Using Multi-Objective Genetic Algorithm”, Wireless Networks 2004.
16. L.Chen, Z.Y.Yang, Z.Q.Xu, “A Degree-Delay-Constrained Genetic Algorithm for Multicast Routing Tree”, Proc. of 4th Int.Conf on Comp. and Inf. Technology (CIT’04), 2004.
17. Y.L.Feng, Z.W.Yu, Y.Pan, “Heuristic Genetic Algorithm for Degree-Constrained Multicast Routing Problem”, Proc. of 3rd Int.Conf.on Machne Learning and Cybernetics, Shangai, 26-29 Aug, 2004.
18. F. Filali, G. Aniba, W. Dabbous, “Efficient Support of IP Multicast in the Next-Generation of GEO Satellite”, IEEE Journal on Selected Areas in Communications, 2004
19. ETSI, “Digital Video Broadcasting; Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering,” EN 302 307 V1.1.1, June 2004; http://www.etsi.org.
20. Xingwei Wang, Hui Cheng, Jiannong Cao, Lianwei Zheng and Ming Huang, “A simulated-annealing-based QoS multicasting algorithm”, International Conference on Communication Technology (ICCT 2003), 9-11 April 2003, Vol.1, pp. 469- 473.
21. N.Skorin-Kapov,M. Kos “The Application of Steiner Trees to Delay Constrained Multicast Routing: a Tabu Search Approach” 71h International Conference on Telecommunications - ConTEL 2003.
22. X. Cui, Chuang Lin, Yaya Wei “A multiobjective Model for QoS Multicast Routing based on Genetic Algorithm”, proc of ICCNMC’03.
23. C. W. Ahn, R. S. Ramakrishna, “Elitism –Based Compact Genetic Algorithms”, IEEE Transactions on Evolutionary Computation, vol. 7, NO. 4, August 2003
24. Xingwei Wang, Hui Cheng, Jiannong Cao, Lianwei Zheng and Ming Huang, “A simulated-annealing-based QoS multicasting algorithm”, International Conference on Communication Technology (ICCT 2003), 9-11 April 2003, Vol.1, pp. 469- 473.
25. ETSI EN 301 790 V1.3.1 (2003-14 03) ETSI TR 101 202: "Digital Video Broadcasting (DVB); Implementation guidelines for Broadcasting".
26. A. Striegel, G. Manimaran, “A Survey of QoS Multicasting Issue”, IEEE Communications Magazine, June 2002.
27. A.T.Haghighat, K.Faez, M.Dehghan, A.Mowlaci, Y.Ghahremani, “Efficient Multicast Routing with Multiple QoS Constraints Based on Genetic Algorithm”, Proc. of the 15th Int. Conf. on Computer Communication, Mumbai, India, pp.181-192, 2002.
28. X.X. Cui,M. Li and T.J. Fang, “Study of population diversity of multiobjective evolutionary algorithm based on immune and entropy principles” in Proc. 2001 Evolu. Compu., May, 2001, pp 1316-1321.
29. W.Zhengying, S.Bingxin, Z.Erdun, “Bandwidth-delay-constrained least-cost multicast routing based on heuristic genetic algorithm,” Computer Communications Journal, issue 24, pp.685-692, 2001.

30. T.C. Tozer, D. Grace, “High-altitude platforms for wireless communications”, Electronics & Communication Engineering Journal, vol.13, no.3, pp.127-137, Jun 2001.

31. J.Neal, R,green, J.Landovskis, “Interactive channel for multimedia satellite networks,” IEEE Commun.Mag., vol.39, pp.192-198, Mar.2001.

32. F. Filali, W. Dabbous, F. Kamoun, “Efficient Planning of Satellite-Terrestrial Hybrid Networks for Multicast Applications”, ICC 2001.

33. Hwa-Chun Li and Shou-Chuan Lai department, “A Simple and Effective core placement method for the CBT multicast routing architecture” of computer Science National Tsing Hua University, TAIWAN, R.O.C, 2001

34. Shingo Ohmori, Communications Research Laboratory, MPT Yasushi Yamao and Nobuo Nakajima” The Future Generations of Mobile Communications Based on Broadband Access Technologies” , Wireless Personal Communications Volume 17, Numbers 2-3, 175-190, 2001.

35. Z. Wang, B. Shi, E. Zhao, “Bandwidth-delay-constrained least-cost multicast routing based on heuristic genetic algorithm”, Computer Communications 24 (2001) 685–692.

36. L.H. Sahasrabuddhe, B. Mukherjee, “Multicast Routing Algorithms and Protocols: A Tutorial”, IEEE Network, Jenuary/February 2000.

37. B. Wang, J. C. Hou, “Multicast Routing and Its QoS Extension:Problems, Algorithms, and Protocols”,IEEE Network, vol. 14, Jan.2000.

38. R. Greelaw, R.Petreschi, “Computing prufer codes efficiently in parallel”, Discrete Applied Mathematics, 2000, Vol. 102, num 3, pp. 205-222

39. R.H.Hwang, W.Y.Do, S.C.Yang, “Multicast Routing Based on Genetic Algorithms,” Journal of Information Science and Engineering, issue 16, pp.885-901, 2000.

40. J.Banks, J.S.Carson, B.L.Nelson, D.M. Nicol, “Discrete Event System Simulatiom,” Aug.2000, Prentice Hall.

41. M. Ramalho, “Intra- and Interdomain Multicast Routing Protocols: A Survey and Taxonomy,” IEEE Commun. Surveys and Tutorials, vol. 3, no. 1, Jan.–Mar. 2000, pp. 2–25.

42. ETSI EN 301 459 V1.2.1 (2000-10): “Satellite Earth Stations and Systems (SES);Harmonized EN for Satellite Interactive Terminals (SIT)and Satellite User Terminals (SUT) transmitting towards satellites in geostationary orbit in the 29,5 to 30,0 GHz frequency bands covering essential requirements under article 3.2 of the R&TTE Directive”

43. ETSI EN 301 192: "Digital Video Broadcasting (DVB); DVB specification for data broadcasting".

44. ETSI TR 101 154: "Digital Video Broadcasting (DVB); Implementation guidelines for the use of MPEG-2 Systems, Video and Audio in satellite, cable and terrestrial broadcasting applications".

45. Dirk Breynaert, “IP over Satellite : DVB-RCS Digital Video Broadcast - Return Channel by Satellite” , Newtec.

46. H.-Y. Tyan, C.-J. Hou, and B. Wang, “On Providing Quality-of-Service Control for Core-Based Multicast Routing,” IEEE Proc. Int’l Conf. Dist. Comp. Sys., June 1999.

47. H.Y.Tyan, J.C.Hou, B.Wang, Y.M.Chen, “QoS Extension to the Core Based Tree Protocol,” the 9th ACM International Workshop on Network and Operating Systems Support for Digital Audio and Video, June 1999.

48. H.-Y. Tyan, C.-J. Hou, and B. Wang, “QoS Extension to the Core-Base Tree Protocol,” Proc. NOSSDAV ’99, June 1999. R. Guerin et al., “QoS Routing Mechanism and OSPF Extensions,” Internet draft, 1998.

49. M. Gen, K. Ida, J. Kim, “A Spanning Tree-Based Genetic Algorithm for Bicriteria Topological Network Design”, In Proceedings of the 5th IEEE Conference on Evolutionary Computation, pages 15{20. IEEE Press, Piscataway, NJ, 1998.

50. Bin Wang and Jennifer C. Hou, The Ohio State University S. Chen and K. Nahrstedt, “Distributed QoS Routing with Imprecise State Information,” Int’l. Conf. Comp., Commun. and Networks (ICCCN ’98), Oct. 1998.

51. D. H. Lorenz and A. Orda, “QoS Routing in Networks with Uncertain Parameters,” Proc. IEEE INFOCOM ’98, 1998.

52. N.F. Maxemchuck, “Video Distribution on multicast Networks” IEEE JSAC, Apr. 97, pp. 357-72

53. R. Guerin and A. Orda, “QoS-Based Routing in Networks with Inaccurate Information: Theory and Algorithms,” Proc. IEEE INFOCOM ’97, Apr. 1997.

54. ETSI EN 300 421: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services". ITU-T Recommendation I.363-5 (1996): "B-ISDN ATM Adaptation Layer specification: Type 5 AAL".

55. W. C. Lee, “Spanning Tree Method for Link State Aggregation in Large Communication Networks,” Proc. IEEE INFOCOM ’95, 1995.

56. Q. Zhu, M. Parsa, J.J. Garcia-Luna-Aceves, “A Source-Based Algorithm for Delay-Constrained Minimum-Cost Multicast”, 1995 IEEE, pp.337-385.

57. V.P. Kompella, J.C. Pasquale, G.C. Polyzos, “Multicast routing for multimedia communication”, IEEE/ACM Transactions on Networking 1 (3) (1993) 286–292.

58. P. Winter, "Steiner Problem in Networks: A Survey," Networks, vol. 17, Summer 1987. pp. 129-67

59. Metropolis, N., Rosenbluth, A.W., Rosenbluth, M. N., Teller, A.H. and Teller, E.; "Equationsof State Calculationsby Fast Computing Machines;" J. ChemicalPhysics, vol. 21 (1953); pp.1087-1092.

List of Publications

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International Journal

J1. De Rango F., Tropea M., Santamaria A.F, Marano S., "Multicast QoS Core-Based Tree Routing Protocol and Genetic Algorithm Over an HAP-Satellite Architecture," in IEEE Transaction on Vehicular Technology, Vol.58, Issue 8, 2009, pp.4447 – 4461

J2. F.De Rango, F.Veltri, M.Tropea, A.F.Santamaria, P.Fazio, A.Malfitano, S.Marano, "Interdisciplinary issues for the management of next generation autonomic wireless systems: nature-inspired techniques and organic computing", International Journal Mobile Network Design and Innovation, 2008.

J3. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "An Enhanced QoS CBT Multicast Routing Protocol based on Genetic Algorithm in a Hybrid HAP-Satellite System," Computer Communication Journal (Elsevier) in December 2007.

International Conference

C1. Mauro Tropea, Fiore Veltri, Floriano De Rango, Amilcare-Francesco Santamaria, Loris Belcastro ,"Two Step based QoS Scheduler for DVB-S2 Satellite System",in IEEE ICC 2011, Kyoto ICC2011 5-9 June 2011

C2. De Rango F., Veltri F., Tropea M., Santamaria A.F., Belcastro L., "An enhanced two-stage packet scheduler for DVB-S2 satellite system based on adaptive strategies". Atti del convegno "milcom", Boston, 2009.

C3. De Rango F., Tropea M., Provato A., Santamaria A.F., Marano S., "ANT Based Routing Algorithm over a HAP Network with Integrated Services " in MICAI 2008: Advances in Artificial Intelligence, Springer, 2008.

C4. De Rango F., Tropea M., Provato A., Santamaria A.F., Marano S., "Minimum Hop Count and Load Balancing Metrics based on Ant Behavior over a HAPS Mesh", in IEEE Global Communications Conference (GLOBECOM 2008), 30 Nov – 4 Dec. 2008, New Orleans, LA, USA

C5. F.De Rango, M.Tropea, A.Provato, A.F.Santamaria, S.Marano, "Multiple Metrics Aware Ant Routing over Hap Mesh Networks," in IEEE Canadian Conference on Electrical and Computer Engineering (CCECE 2008), Niagara Falls, Ontario, Canada, May 4-7, 2008.

C6. F.De Rango, A.F.Santamaria, M.Tropea, S.Marano, "Meta-heuristics methods for a NP-Complete networking problem," 66th IEEE Vehicular Technology Conference (VTC Fall 2008), Calgary, Alberta, Canada, 21-24 Sept. 2008.

C7. F.De Rango, M.Tropea, A.Provato, A.F.Santamaria, S.Marano, "Minimum Hop Count and Load Balancing Metrics on Ant Behavior over a Haps Mesh," IEEE Global Telecommunications Conference (Globecom'08), New Orleans, LA, USA, 30 nov.-4 Dec. 2008.

C8. F.De Rango, A.F.Santamaria, F.Veltri, M.Tropea, L.Belcastro, S.Marano, "An Auto-Adaptive DVB-S2 architecture with an Enhanced ACM Policy Manager," KA and Broadband Communication Conf.(KaBand'08), Matera, Italy, 24-26 Sept., 2008.

C9. F.De Rango, M.Tropea, A.F.Santamaria, F.Veltri, P.Fazio, S.Marano, "Multi-Mode DVB-RCS Satellite Terminal with Software Defined Radio," IEEE Wireless Communication and Networking Conference (WCNC 2007), Hong Kong, 11-15 March, 2007.

C10. F.De Rango, F.Veltri, P.Fazio, A.F.Santamaria, M.Tropea, S.Marano, "FER Regression Analysis of DS-UWB-based WPAN," Wireless Telecommunication Symposium (WTS 2007), Pomona, CA, USA, Apr.27-29, 2007.

C11. F.De Rango, F.Veltri, P.Fazio, A.F.Santamaria, M.Tropea, S.Marano, "Multi-Satellite DVB-RCS System with RCST based on Software Defined Radio," 65th IEEE Vehicular Technology Conference (VTC Fall 2007), Baltimore, USA, 22-25 Oct. 2007

C12. F.De Rango, M.Tropea, A.Provato, A.F.Santamaria, S.Marano, "Routing Algorithm based on Swarm Intelligence over a Hap Constellation," in 10th Int. Symposium on Performance Eval. Of Computer and Telecommunication Systems (SPECTS'07), 16-18 July, San Diego, CA, USA.

C13. F.De Rango, A.F.Santamaria, M.Tropea, G.Milanese, S.Marano, "QoS Multicast Routing Protocol for Broadband hierarchal network," in Ka and Broadband Communication Conference (KaBand'07), 24-26 Sept. 2007, Turin, Italy.

C14. F.De Rango, F.Veltri, A.F.Santamaria, M.Tropea, S.Marano"Software Defined Radio-based Multi-Mode DVB-RCS Terminals," Milcom'07, 29-31 Oct., Orlando, Florida.

C15. F.De Rango, M.Tropea, A.Provato, A.F.Santamaria, S.Marano, "Multi-Constraints Routing Algorithm based on Swarm Intelligence over High Altitude Platforms," Int. Workshop on Nature Inspired Cooperative Strategies for Optimization, Acireale, Sicily (Italy), November 8-10, 2007.

C16. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "A QoS Multicast Genetic Algorithm in a Hybrid HAP/DVB-RCS Satellite Platform," 13rd International Conference on Telecommunications (ICT 2006), Madeira Island, Portugal, May 9-12, 2006.

C17. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "QoS Core Based Tree Multicast Routing based on Genetic Algorithm in a Hybrid HAP-Satellite Architecture," Int. Symposium on Performance Evaluation of Comp. and Telecomm. Systems (SPECTS'06), July 31 – Aug.2, 2006.

C18. F.De Rango, M.Tropea, P.Fazio, F.Veltri, A.F.Santamaria, S.Marano, "Software Defined Radio based Multi-Mode Satellite Terminal over DVB-RCS Platform," 12th Ka and Broadband CommunicationsConference, Naples, Italy, Sept. 27-29, 2006.

C19. F.De Rango, M.Tropea, A.F.Santamaria, S.Marano, "QoS Multicast over Hybrid HAP-Satellite Networks," 12th Ka and Broadband Communications Conference, Naples, Italy,

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