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ACTIVITY IN SATELLITE RESOURCE MANAGEMENT

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2.1 Introduction

The efficient exploitation of common resources is an important aspect in networking, at all protocol layers. In satellite networking, in particular, there are a number of physical layer issues that have to be addressed in the design of the system:

- Fading
- Delay spread
- Doppler shift
- Limited spectrum
- Path loss and thermal noise.

Given these issues, the goal of *Radio Resource Management* (RRM) is to optimize bandwidth (capacity) utilization and *Quality of Service* (QoS), in the presence of traffic flows generated by services with different requirements. Whenever resources or their modifications are requested, the goal of RRM is to optimize request satisfaction and, at the same time, to try to maintain a certain degree of fairness among all users.

End-user QoS in satellite/terrestrial networks depends on the QoS achieved at each layer of the network, based on satellite-dependent and independent functions to be performed at the layer interfaces. The co-operation of all network layers from top to bottom, as well as of every network element, is fundamental. Each layer should use efficient technologies and counteract any performance degradation factors in order to fulfill the user performance requirements.

As an example of co-operative work, the following actions are considered in order to optimize system performance.

- Bandwidth-efficient modulation and encoding schemes have to be used at the *physical layer*, to improve the *Bit Error Rate* (BER) and the power level performance under poor weather conditions, such as heavy rain.
- Guaranteed bandwidth must be provided at the *data link layer* by using efficient bandwidth-on-demand multiple access schemes and by studying the interaction of mechanisms in the presence of congestion and fading. The provision of a specific bandwidth to be offered by the physical layer to the upper layers implies the existence of a bandwidth allocation scheme that shares the available bandwidth among the different user terminals with different traffic classes.
- The *network layer* is the lowest layer that deals with source-to-destination delivery of connection requests (in circuit-switched networks) or packets (in packet-switched networks); it must know about the topology of the communication subnet and choose the appropriate paths through it. Efficient routing policies must be implemented at this level in order to select paths with the lowest congestion probability. Regarding IP traffic management, user mobility has to be adequately taken into account. Hence, network layer protocols must provide a prioritized management for traffic coming from users that incur in handover phases (such as in the presence of non-GEO satellites). Additionally, mechanisms for IP-layer QoS provision have to be adequately mapped to MAC layer RRM protocols); indeed, besides considering the protocol layering overhead, the service capacity to network layer queues is provided by MAC queues that, generally, are not in one-to-one correspondence to the former ones. This point will be highlighted in some detail in Chapter 8, Section 3.
- At the *transport layer*, TCP connections, which currently constitute the bulk of the traffic transferred in the Internet, tend to occupy all the available bandwidth. The nature of most TCP traffic is asymmetric, with data flowing in one direction and acknowledgments in the opposite direction. This translates into different bandwidth requirements from the sender and the receiver, respectively. Bandwidth assignment and link quality have a strong impact on the TCP goodput.
- At the *application layer*, different traffic types (e.g., real-time traffic and non-real-time traffic) must have specific service level agreements and a

monitoring action has to be performed jointly with the network layer in order to adaptively modify the service priority.

Several strategies for the optimization of resource management have been investigated; resource management schemes are strongly related to the traffic. For example, supporting high bit-rate switched traffic over the radio interface and maintaining the QoS requested by single applications put new requirements on resource management. In addition to the variation in the demands due to the multimedia traffic nature, there are other system variations that have a strong impact on the adopted RRM technique. These include changes in the link quality experienced by each terminal due to the weather conditions, mobility, jamming, and other factors. As a matter of fact, RRM policies, along with network planning and air interface design, determine QoS performance at the network level and the individual user level. The RRM techniques encompass frequency and/or time channels, transmitted power, and access to base stations. The goal is to control the amount of resources assigned to each user to maximize some performance indicators, such as the total network throughput, the total resource utilization and the total network revenue, or to minimize other indicators, such as the end-to-end delay and the real-time transmission jitter, subject to some constrains such as the maximum call dropping rate and/or the minimum signal-to-noise ratio.

The better the RRM technique adopted, the better the performance of the overall system. It is however clear that the overall performance might be improved by considering the co-operation of several protocol layers together, which is commonly called "*cross-layer approach*". In this case, new functions need to be introduced in the protocol stack to enable interactions even between non-adjacent protocol layers. In designing a cross-layer architecture for satellite networks (as in other cross-layer designs), the architectural implications and the principle of *layer separation* [1] should be carefully considered. Relatively few studies have been published to-date on cross-layer optimization in a satellite context (a recent survey can be found in [2]). Cross-layer approaches for the satellite environment are deeply surveyed in Chapter 4 and some numerical results are provided in the following Chapters.

Comprehensive surveys on satellite RRM can be found in [3]-[7]. Reference [8] provides an account on *Call Admission Control* (CAC) in the more general wireless environment. A possible grouping of the RRM techniques in the literature can be attempted in the following three categories:

1. *Frequency/time/space resource allocation schemes* (such as channel allocation, scheduling, transmission and coding rate control, beam and bandwidth allocation);
2. *Power allocation and control schemes*, which control the transmitter power;
3. CAC and *handover algorithms*, which control the access port connection.

An overview of the most recent research activities in the RRM field follows. Of course, the overview cannot be exhaustive, as new material is continuously produced.

2.2 Frequency/time/space resource allocation schemes

Papers [9] and [10] treat the RRM subject from the scheduling perspective.

In [9], the authors propose a transmission scheduling method that deals with the problem of determining *Super-frame Length* (SL), when allocating the return channel resources to the capacity requests from satellite interactive terminals. A main purpose of this method is to minimize the SL in order to reduce scheduling-wait-time as well as to improve resource utilization. This method provides great flexibility in scheduling, by limiting the SL as much as possible, and also achieves high resource utilization, by smoothing the time-varying demands with an overload control.

In [10], the packet-scheduling function has been investigated within the access scheme of a unidirectional satellite system, providing point-to-multipoint services to mobile users. It is interesting how the authors here regard the satellite system as an overlay multicast/broadcast layer, which complements point-to-point 3^{rd} *Generation* (3G) mobile terrestrial networks. The satellite access scheme features maximum commonalties with the *Frequency Division Duplexing* (FDD) air interface of the *Terrestrial Universal Mobile Telecommunications System* (T-UMTS), also known as *Wideband Code Division Multiple Access* (W-CDMA), thus enabling close integration with the terrestrial 3G mobile networks and cost-efficient handset implementations. Attention focuses on one of the radio resource management entities relevant to this interface: the packet scheduler. The lack of channel-state information and the point-to-multipoint service set the difference between the packet scheduler in the satellite radio interface from its counterpart in point-to-point terrestrial mobile networks. The authors formulate the scheduler tasks and describe adaptations of two well-known scheduling disciplines, multilevel priority queuing and weighted fair queuing schemes, as candidates for the time-scheduling function.

Papers from [11] to [15] address the RRM problem from the transmission and rate control point of view.

Reference [11] models the Ka band channel by using a Markov process to capture the impact of the time correlation in weather conditions. A rate adaptation algorithm is developed to optimize the data rate, based on real-time feedback on the measured channel conditions. The algorithm achieves both higher throughput and link availability as compared to a constant rate scheme. In [12], the authors consider a resource allocation problem for a satellite network, where variations of fading conditions are added to those of traffic load. Two novel optimization approaches are addressed. The first one, considered in more detail in [13], is based on the minimization over a discrete constraint set, by using an estimate of the gradient, obtained through a "relaxed continuous extension" of the performance measure. The computation of the gradient estimation relies on the infinitesimal perturbation analysis. The second approach adopts an open-loop feedback control strategy, aimed at providing optimal reallocation strategies as functions of the state of the network. A functional optimization problem is proposed, and a neural network-based technique is used in order to approximate its solution.

In [14] and [15], the authors propose an adaptive global strategy, which handles link congestion and channel conditions in multimedia satellite networks. The overall control system also includes CAC, an aspect mentioned later in this Chapter. However, we include these papers in the present group, in order to emphasize the presence of adaptive coding. In [15], in particular, a performance comparison is presented for a fixed admission control strategy versus the new adaptive CAC scheme for a *Direct Broadcast Satellite* (DBS) network with *Return Channel System* (DBS-RCS). The traffic considered includes both *Available Bit Rate* (ABR) traffic and *Variable Bit Rate* (VBR) traffic. The dynamic channel conditions in the satellite link consider time-varying error rates due to external effects, such as rain. In order to maximize the resource utilization, for both fixed and adaptive approaches, assignments of the VBR services are determined based on the estimated statistical multiplexing gain and other system attributes, namely, video source, data transmission and channel coding rates.

Papers from [16] to [37] deal with the RRM topic from the bandwidth allocation point of view.

In interactive satellite networks, the delay between a request and the reception of the reply is a key issue, due to the basic latency of the satellite link. The solution offered in [16],[17] for GEO satellites comprises a prediction-based resource-allocation policy and a scheduling time period as short as possible. A resource-allocation problem is mathematically formulated as a non-linear integer programming problem, considering uncertain future traffic conditions, and the author develops a real-time heuristic solution algorithm. Computational complexity analysis and extensive simulation results demonstrate the very good performance of the proposed method in terms of computational efficiency and heuristic solution quality.

In [18],[19] the authors propose a scheme for *Dynamic Bandwidth Allocation Capabilities* (DBAC) that is not based on classical circuit-switching, but allows changing the capacity of each connection dynamically without tearing down and setting up the connection. The analysis of the proposed DBAC scheme shows a significant increase in the overall utilization of the capacity, compared to a plain circuit-switching solution.

The work in reference [20] focuses on resource allocation and CAC issues in broadband satellite networks; the authors propose a resource allocation algorithm that integrates three classes of services at the MAC layer: *Constant Bit Rate* (CBR), bursty data, and best effort services. They propose a *Double-Movable Boundary Strategy* (DMBS) in order to establish a resource-sharing policy among these service classes over the satellite uplink channel. DMBS is a dynamically controlled boundary policy, which adapts the allocation decision to variable network loading conditions. CAC and bandwidth allocation decisions are taken at the beginning of each control period, after monitoring the filling level of the traffic request queues. The authors define a threshold level for the bursty data request queue in order to regulate the CAC process. The impact of the queue threshold value on the performance of the DMBS allocation policy is evaluated. A dynamic variation of this metric is also proposed to enhance the system response for interactive applications.

Reference [21] provides an overview of *Broadband Satellite Access* (BSA) systems, with an emphasis on resource management and interworking techniques to support IP-based multimedia services. Some key innovations are described, including *Combined Free/Demand Assignment Multiple Access* (CF/DAMA) for dynamic satellite bandwidth allocation, and an architecture for DiffServ provisioning over BSA systems. A CF/DAMA scheme for dynamic satellite bandwidth allocation is also the subject of the work proposed in [22]; this scheme allows the return channel capacity to be efficiently shared among many user terminals.

In [23], the resource allocation problem that arises in the context of a *Medium Earth Orbit* (MEO) satellite system with half-duplex communication capabilities is addressed. MEO satellite systems are characterized by relatively large propagation delays and intra-beam delay variations, which result in resource consumption. The authors propose a channel classification scheme, in which the available carriers are partitioned into classes and each class is associated with a range of satellite propagation delays.

References [24] and [25] deal with the problem of QoS provisioning for packet traffic. In [24], the authors address the problem by considering a resource allocation scheme that takes advantage of proper statistical traffic modeling to predict future bandwidth requests. This approach takes into consideration DiffServ-based traffic management to guarantee QoS priority among different users. Moreover, the satellite onboard switching problem is also addressed by considering a suitable implementation of the DiffServ policy based on a cellular neural network.

In [25], the problem of providing guaranteed QoS connections over a *Multi Frequency - Time Division Multiple Access* (MF-TDMA) system that employs *Differential Phase Shift Keying* (DPSK) is studied. The problem is divided into two aspects: resource calculation and resource allocation. The authors present algorithms for performing these two tasks and evaluate their performance in the case of a Milstar *Extremely High Frequency - Satellite Communication* (EHF-SATCOM) system.

References [26] and [27] present an algorithm for resource allocation in satellite networks to obtain time/frequency plans for a set of terminals with a known geometric configuration under interference constraints. The goal is to maximize the system throughput while guaranteeing that the different types of demands are satisfied, each type using a different amount of bandwidth. The proposed algorithm relies on two main techniques. The first generates admissible configurations for the interference constraints, whereas the second uses linear and integer programming with column generation.

In [28], the authors consider the problem of how a *Geostationary Earth Orbit* (GEO) satellite should assign bandwidth to several service providers (operators) so as to meet some minimum requirements on one hand, and to perform the allocation in a fair way on the other. They provide a computational method to optimize allocation fairness in polynomial time, taking practical issues into account.

References [29] and [30] consider the problem of allocating the uplink bandwidth of a satellite transponder among hierarchies of Earth stations, for guaranteed bandwidth and best-effort traffic types. CAC actions are taken locally at the Earth stations within the allocated bandwidth partition, which is recomputed either periodically or upon request, by considering dynamic variations in traffic and channel parameters (with a cross-layer interaction between physical and MAC layers).

The work in [31],[32] proposes a new DiffServ-based scheme of bandwidth allocation during congestion, termed *Proportional Allocation of Bandwidth* (PAB). This method can be used in satellite networks based on GEO, MEO, and LEO (*Low Earth Orbit*) constellations, in order to transport IP traffic and to provide QoS. In PAB, during congestion, all flows get a share of IP available bandwidth, proportional to their subscribed information rate.

Reference [33] considers an architecture to interconnect remotely located heterogeneous terrestrial distribution nodes in a mesh topology, by means of an onboard regenerative satellite. An emulated DVB-S (*Digital Video Broadcasting via Satellite*) regenerative environment is created, by using an actual transparent GEO satellite. Furthermore, a dynamic bandwidth mechanism is proposed, to be applied directly on the DVB-S stream of the uplink of each distribution node. This mechanism enables the provision of interactive IP-based multimedia services, at a guaranteed QoS.

The work in [34] focuses on dynamic resource allocation algorithms for sharing the limited uplink resources of a future satellite system among many bursty users with varying QoS requirements. The data rates provided to each terminal are selected to differentiate multiple QoS priority levels, to provide fairness and to maximize system capacity under time-varying channel conditions and traffic loads.

In [35], *Weighted Fair Bandwidth-on-Demand* (WFBoD) technique is defined and analyzed. It is a resource management process for broadband multimedia GEO satellite systems that provides fair and efficient resource allocation, coupled with a well-defined MAC-level QoS framework (compatible with ATM and IP QoS frameworks) and a multi-level service segregation into a large number of users with diverse characteristics. WFBoD is also integrated with the CAC process. Simulation results show that WFBoD can guarantee QoS for both non-real-time and real-time VBR flows.

A consolidated approach for *Voice over IP* (VoIP) over satellite networks based on the ETSI DVB-RCS standard is adopted in [36]. This paper addresses the role of *Bandwidth on Demand* (BoD) in the optimization of VoIP bandwidth allocation, and assesses the impact of BoD mechanisms on voice quality. The tradeoff between voice quality and bandwidth efficiency is investigated under different DVB-RCS-specific capacity request/allocation strategies; it is demonstrated that DVB-RCS provides an efficient platform for the integrated support of a variety of satellite VoIP applications.

Reference [37] compares BoD in an MF-TDMA environment and *Single Carrier Per Channel* (SCPC) from a practical perspective and evaluates the economical advantages of BoD.

2.3 Power allocation and control schemes

Normally, the literature considers three types of uplink power control techniques [5]:

- *Open loop.* One station receives its own transmission carrier (relayed by the satellite) and relies on its measurement of beacon fading in the downlink, in order to perform uplink power control.
- *Closed loop.* Two Earth stations lie within the same beam coverage and an Earth station can receive its own transmission carrier. Uplink power control based on this carrier is erroneous due to changes in input and output backoffs under uplink and downlink fading. It must be based on the reception of a distinct carrier transmitted by another station.
- *Feedback loop.* A central control station monitors the levels of all carriers it receives, and commands the affected Earth stations to adjust their uplink powers accordingly. This technique has inherent control delays, and requires more Earth segment and space segment resources.

Regarding downlink, power control allocates additional power to the transmission carrier(s) at the satellite in order to compensate for rain attenuation. As downlink fading occurs, downlink carrier power degrades and sky noise temperature seen by the Earth station increases. Power control correction is required to maintain carrier to noise ratio.

Papers from [38] to [41] treat RRM from the power allocation and control scheme perspective.

In [38], the authors consider the problem of using narrow transmission spot-beams on the satellite to support a broad spectrum of users with small terminals at high rates. Since satellite transmitter resources are expensive and there can be many spot-beam coverage cells within the satellite service area, it is attractive to look for some form of agile-scanning beam system and to time-share these precious resources. An optimized design of both the multi-beam antenna pattern and the scheduling can further improve the efficiency of transmission and power management. The advantage of parallel multi-beams in terms of spectral efficiency and power gain is shown, and the issue of multi-beam power allocation based on traffic demands and channel conditions over satellite downlinks with power and delay constraints is addressed. The study indicates that the use of a parallel multi-beam scheme with optimum power allocation can achieve a substantial power gain and a reasonable proportional fairness. By coupling power allocation with multi-beam scheduling when there are less active beams than cells, the authors show that a modest number of active parallel beams suffices to cover many cells efficiently.

In [39], the author analyzes a power-sharing multiple-beam mobile satellite system in the Ka band with high traffic variations from one beam to another. In order to cope with the multiple-beam varying traffic problem, the author proposes an offset reflector antenna, fed through an equal phase-shift active array. This active array consists of hundreds to thousands of equal phase-shift elements.

A power allocation policy is developed in [40] for a multi-beam satellite downlink, which transmits data to different ground locations over time-varying channels. The packets destined to each ground location are stored in separate queues and the server rate for each queue depends on the power allocated to that server and the channel state, according to a concave rate-power curve.

A method for satellite network configuration is proposed in [41]. It controls the transmitted power of multiple Earth stations, and establishes the received power-differences among them to generate the capture effect.

2.4 CAC and handover algorithms

This topic is widely treated in Chapter 6. This Chapter only aims at providing an overview.

Arriving calls are granted/denied access to the network by the CAC scheme based on predefined criteria, taking into consideration network loading conditions. The traffic of admitted calls is then controlled by other RRM techniques, such as scheduling, handover, power, and rate control schemes. CAC is extensively studied as an essential tool for congestion control and QoS provisioning. In terrestrial wireless networks, CAC is more sophisticate than in cabled networks, due to unique features of wireless networks such as multiple access channel interference, channel impairments, handover requirements and limited bandwidth. As in terrestrial wireless networks [8], in satellite networks there are several reasons for using CAC schemes, including:

- *To control the handover failure probability in LEO constellations.* Blocking a new call is surely better than dropping an in-progress call; regardless of the CAC procedure used, the criterion is maintaining active calls in progress and blocking new calls that might lead to an increase of the call dropping probability.
- *To limit the network traffic level to guarantee packet-level QoS parameters (packet delay, delay jitter and throughput).* Some CAC procedures can estimate packet delay and delay jitter from available resources in multiple-class networks (see [8] and references [130],[131] therein).
- *To ensure a minimum transmission rate.* This can be achieved either by limiting network load (see [8] and references [7],[67],[132] therein), by minimizing the transmission rate degradation (i.e., the condition where the transmission rate is below a minimum value) (see [8] and references [128],[133] therein) or by estimating the allocated transmission rate as an admission criterion (see [8] and reference [101] therein).

CAC schemes can be classified according to various design options [8] (centralization, information scale, service dimension, optimization, decision time, information type, information granularity, considered link).

A number of policies have been derived for resource sharing in CAC, first for cabled networks, and then for wireless networks in general. The simplest CAC rule is *Complete Sharing* (CS), i.e., connections are simply admitted if sufficient resources are available at the time of the request, without considering the importance of a connection when they are allocated. In the CS policy, the only system constraint is the overall capacity C. In the presence of multiple services, this policy may suffer from some problems such as unfairness, in the sense that it can monopolize the resources, it may lead to poor resource utilization and, finally, it may yield poor long-run average revenue. As an almost opposite situation, in the *Complete Partitioning* (CP) type of policies, every traffic class is allocated a set of resources that can be used only by that class. Other policies have been derived to provide optimized access to resources, and Ross [42] provides an extensive discussion about a number of different solutions. Actually, optimal approaches should be based on Markov decision processes, given a certain cost function to be minimized (or maximized) as a performance index; however, they must take into detailed account any allowable network state and state transition, which is impractical even for networks of modest complexity. The functional form of the optimal policies is usually unknown. Therefore, a set of generally sub-optimal policies with fixed structure (which can be often described by a set of parameters) has been developed. They are simpler to implement and, in some special cases, do correspond to the optimal one; among others, we can cite the above mentioned CP, *Trunk Reservation* (TR) [43], *Guaranteed Minimum* (GM) [44], and *Upper Limit* (UL) policies [44],[45]. Comparisons have been made between these policies and the optimal one. The results indicate that CP, TR, GM, and UL policies outperform the CS one when significant differences among classes exist in requirements for bandwidth and offered load [46]. Obviously, once one of such fixed-structure policies has been selected, parametric optimization can be adopted in order to choose the "best" values of parameters that minimize a given cost function (or maximize a performance index).

As already mentioned, reference [15], besides considering adaptive coding, also treats the RRM problem from the CAC point of view. This is also done in [20] and [29],[30], among others. Reference [8] provides an account on CAC in the more general wireless environment.

In [47], the authors combine CAC with the issue of optimal energy allocation for communication satellites. The objective is to choose the requests for transmission to serve so that the expected total reward is maximized. The special case of a single energy-constrained satellite is considered. Rewards and demands from users for transmission (energy) are random and known only at request time. Using a dynamic programming approach, an optimal policy is derived that is characterized in terms of thresholds. Furthermore, in the special case where energy demand is unlimited, an optimal policy is obtained in closed form.

In [48], a real-time traffic handling strategy, including distributed CAC and traffic resource management schemes, is harmonized with an in-band signaling technique for burst-based bandwidth requests and an effective policy for the allocation of radio resources.

2.4.1 Handover algorithms

In wireless mobile networks, many users share radio bandwidth. An important property of the network is that user devices change their access points several times. As their coverage area changes continuously, in order to maintain connectivity, end-users must switch between spot-beams and satellites, and, thus frequent intra- and inter-satellite handover attempts occur. This fact causes technical problems, requiring fair sharing of bandwidth between handover connections and new connections. One of the main problems to be solved in RRM is the handover management strategy in order to provide low call dropping probability and to keep high resource utilization.

Several approaches for handover prioritization proposed for terrestrial cellular systems have been studied in the recent literature for mobile satellite systems. The solutions include the guard channel scheme, a handover queuing where the highest priority is offered to handover calls, which are organized in a separate queue, and novel CAC algorithms, taking into account handover calls.

In [49], user location information is exploited for adaptive bandwidth reservation for handover calls. In a beam, bandwidth reservation for handover is allocated adaptively, by calculating the possible handovers from neighboring beams. A new call request is accepted if its originated beam has sufficient amount of available bandwidth for new calls.

The key idea of the algorithm in [50] is that bandwidth has to be reserved in a particular number of beams S the call may handover into, in order to prevent handover dropping during a call. The balance between new call blocking and handover call blocking depends on the selection of predetermined threshold parameters for new and handover calls.

In [51], a probabilistic resource reservation strategy for real-time services was proposed, based on the concept of sliding windows to predict the necessary amount of reserved bandwidth for a new call in future handover beams.

In [52], CAC and handover are based on user location. The system traces all user locations in each beam and updates user handover-blocking parameters.

Reference [53] proposes an intra-satellite handover management scheme for LEO satellites, called Q-WIN, specifically tailored to the QoS needs of multimedia applications. This scheme is based on priority queues, combined with the sliding virtual window concept for call admission. Simulation results confirm that, compared to the allocation schemes, Q-WIN offers low *Call Dropping Probability* (CDP), thus providing for reliable handover of calls in progress, acceptable *Call Blocking Probability* (CBP) for new calls and high resource utilization.

In [54], a guaranteed handover scheme is proposed. According to this method a new call is admitted in the network only if there is an available channel in the current cell and, simultaneously, in the first transit cell. When the first handover occurs, a channel-reservation request is issued to the next candidate transit cell, and so on. If all channels are busy, the request is queued in a FIFO list, until the next handover occurrence. The call is not forced to terminate provided that an available channel has been reserved in the meanwhile.

In [55], different queuing policies for handover requests are proposed. The handover requests, queued up to a maximum time interval (which is a function of the overlapping area of contiguous cells), are served according to a FIFO or a *Last Useful Instant* (LUI) scheme (that is, a handover request is queued ahead of any other requests already in the queue that have a longer residual lifetime).

In [56], a novel inter-satellite handover management scheme tailored for multimedia LEO satellite systems is proposed and evaluated. This scheme relies on queuing handover requests of different service classes in separate queues. The queue that stores handover requests of real-time services receives higher priority.

2.5 RRM modeling and simulation

There is a wealth of work on RRM modeling and simulation. References from [57] to [60] are just a few examples.

In [57], the authors describe the modeling and simulation of an FDMA (*Frequency Division Multiple Access*) satellite BoD service. This class of resource allocation processes, which includes BoD applications, is identified and compared with common resource allocation processes. Within this class, the bidirectional and possibly asymmetric nature of resource requests, the existence of both booked (advance notification) and immediate resource requests, the allowance of modifications to resource requests and the multiple resource constraints (e.g., bandwidth and power) present unique modeling challenges. In particular, we can consider three fundamental components: modeling the resource requests, modeling the fundamental resource allocation algorithm and modeling the processing of individual resource requests.

In [58], the authors focus on modeling and evaluating the bandwidth requirements of the next-generation of satellite communication technologies, which will support future aeronautical applications. The authors' interest is on the real-time delivery of high-resolution weather maps to the cockpit as a particularly demanding future application. In such scenario, the use of LEO and GEO satellite networks for efficient data delivery is investigated. The authors propose a joint uni-cast and broadcast communication technique that offers bandwidth reduction.

In [59], a new analytical model for equal allocation of divisible computation and communication load is developed. Equal load allocation is attractive in multiple processor systems when real-time information on processor and link capacity, which is necessary for optimal scheduling, is not available. This model includes a detailed accounting of solution reporting time.

Reference [60] presents a generalized notation as well as graph algorithms for resource management problems. Impairment graphs can be used for frequency planning, whereas flow graphs are suitable for channel access problems. To evaluate the performance of the resource management, service criteria (such as blocking or *Carrier-to-Interference ratio*, C/I) or efficiency criteria (bandwidth requirements) are derived from the graphs. The resource management techniques are applied to satellite networks with non-GEO orbits that entail time-varying network topologies. As a simple example, the channel assignment and capacity optimization of the EuroSkyWay system are shown. For a deeper inspection, a comparison of *Fixed, Dynamic and Hybrid Channel Allocation* schemes (FCA, DCA, HCA) for a typical MEO satellite scenario is provided. The author also investigates satellite diversity and its impact on bandwidth requirement and transmission quality.

2.6 Related projects in Europe

A number of satellite-related projects have been funded by the European Commission in both the *Fifth* and the *Sixth Framework Programmes* (FP5, FP6), as well as in COST Actions. In sub-Sections 2.6.1-2.6.4, we limit our overview to a few FP6 projects. Additional information can be found in *http://cordis.europe.eu.int/en/home.html*. Finally, sub-Section 2.6.5 mentions a recent COST Action and sub-Section 2.6.6 describes a new initiative in the satellite field for the FP7 EU programme.

2.6.1 TWISTER: Terrestrial Wireless Infrastructure integrated with Satellite Telecommunications for E-Rural applications

http://www.twister-project.net/

TWISTER is a project led by EADS Astrium and was selected for co-funding by the European Commission in the 1st call for proposals of the Aeronautics and Space priority of FP6.

This project started on February 1, 2004, and will operate validation sites throughout Europe for 3 years, through the deployment of up to 105 satellite access points in combination with radio networks. These validation sites support innovative applications to meet the specific needs of rural user communities in the domains of agriculture, education, community services, healthcare and e-business. This project emphasizes usages that benefit from broadband access. The objective of TWISTER is to support the development and widespread adoption of satellite communication services (like educational and health care services between islands, or e-business) to deliver broadband services to rural areas. User satisfaction is evaluated to propose improvements and to specify a roadmap for further services deployment. The integration of space-based infrastructure with terrestrial systems aims at achieving a seamless broadband coverage in rural areas. TWISTER investigates a number of hybrid satellite-wireless architectures and validates their on-site performance. The TWISTER consortium, involving many actors in the telecom value chain (user communities, service providers, satellite operators, equipment manufacturers) creates the necessary conditions to deploy successfully such satellite solutions over Europe as a complement to terrestrial networks for the benefit of the population and the economy.

2.6.2 MAESTRO: Mobile Applications & sErvices based on Satellite & Terrestrial inteRwOrking

http://ist-maestro.dyndns.org/MAESTRO

The MAESTRO project aims at studying technical implementations of innovative mobile satellite systems, targeting close integration and interworking with 3G and beyond-3G mobile terrestrial networks. MAESTRO seeks to specify and to validate the most critical services, features, and functions of satellite system architectures, achieving the highest possible degree of integration with terrestrial infrastructures. It aims not only at assessing the satellite system technical and economical feasibility, but also at highlighting their competitive assets on the way they complement terrestrial solutions.

In the frame of the MAESTRO project, innovative and convergent solutions pursue: (*i*) the successful and cost effective deployment of 3G multimedia services over mobile satellite networks; (*ii*) the reduction of the digital divide between urban and rural areas and regions by ensuring service continuity over heterogeneous GPRS/UMTS networks.

2.6.3 SatNEx: Satellite Network of Excellence

http://www.satnex.org

SatNEx is an FP6 research *Network of Excellence* (NoE), funded by the European Commission, which combines the research excellence of 22 major players in the field of satellite communications [61]-[63]. The primary goal of SatNEx is to achieve a long-lasting integration of European research in satellite communications, and to develop a common knowledge base. This collected expertise will support the European satellite industry through standardization, collaboration/consultancy and training. Through co-operation of outstanding universities and research organizations with excellent expertise in satellite communications, SatNEx is building a European virtual center of excellence in satellite communications and will contribute to the realization of the *European Research Area* (ERA). A dedicated satellite platform links partners in a broadcast, multicast or unicast configuration, providing training and video-conferencing capabilities, and promoting the simplicity and cost-effectiveness of using satellites for this purpose. SatNEx has established an advisory board incorporating key representatives of the European space industry, satellite service providers, and standardization and regulation organizations. SatNEx is steered by these players in providing a critical mass of resources and expertise, to make Europe a world force in the field of satellite communications. Part of the SatNEx mission is to disseminate internal research and expertise.

2.6.4 NEWCOM: Network of Excellence in Wireless COMmunications

https://newcom.ismb.it/public/index.jsp

NEWCOM is a European NoE that links in a cooperative way many leading research groups addressing the strategic objective “Mobile and wireless systems beyond 3G”, a frontier research area of the priority thematic area of IST. This network involves 54 partners from 18 countries, comprising 40 universities and 14 companies. The major objective is a ‘distributed European university’ with common research projects and, in the longer term, a shared doctoral school. This NoE is devoted to the terrestrial wireless environment. However, some of the research topics, such as cross-layer optimization and reconfigurable radio, share common aspects with the satellite world.

2.6.5 VIRTUOUS: Virtual Home UMTS on Satellite

http://www.ebanet.it/virtuous.htm

The VIRTUOUS project [64], ended in 2002, aimed at identifying, designing and demonstrating a feasible, pragmatic, smooth migration path towards *Terrestrial and Satellite UMTS* (T-UMTS and S-UMTS). VIRTUOUS pursued the achievement of the following specific objectives:

- Design, development and implementation of both a URAN (*UMTS Radio Access Network*) *Radio Technology Independent* part and two URAN *Radio Technology Dependent* parts, able to handle a terrestrial and a satellite link, respectively;
- Development of two hardware test beds, representative of satellite and terrestrial UMTS physical layers, respectively;
- Definition of the S-UMTS components;
- Design, development and implementation of appropriate terminal and network *Inter-Working Units* (IWUs), aiming at integrating the GPRS and the UMTS segments;
- Implementation, integration and testing of a demonstrator including three segments: GPRS, terrestrial UMTS and satellite UMTS;
- Trials of meaningful UMTS services, with voice over IP as a candidate application.

2.6.6 COST Actions

European *Co-operation in the field of Scientific and Technical Research* (COST) is an intergovernmental framework for the co-ordination of nationally-funded research at European level, based on a flexible institutional structure. Established in 1971, COST has developed into one of the largest frameworks for research co-operation. The 34 member countries of COST include the 25 EU member states, Bulgaria, Croatia, Iceland, Norway, Romania, Serbia and Montenegro, FYR of Macedonia, Switzerland and Turkey. Moreover, Israel is a co-operating state. COST also welcomes Institutions from non-COST countries to join individual actions for mutual benefit. COST networks are called Actions. Co-operation takes the form of concerted activities, i.e., the co-ordination of nationally funded research activities. Some of the early COST actions have helped to pave the way for other European research programs, such as the EU Framework Programs (launched in 1983) and the EUREKA initiative (started in 1985; see *http://www.eureka.be*). COST plays an important role in scientific and technical co-operation in Europe, encouraging European synergy and networking and helping further European integration.

COST covers a wide range of scientific and technological areas: agriculture, biotechnology and food sciences, chemistry, environment, forests and forestry products, materials, medicine and health, meteorology, physics, social sciences and humanities, *Telecommunications, Information Science and Technology* (TIST), transport and urban civil engineering.

For more information, the reader may visit the Web site *http://www.cost.esf.org/index.php*.

COST Action 272: "Packet-Oriented Service Delivery via Satellite"

http://www.tesa.prd.fr/cost272/

This COST Action ended in the first half of 2005 and was entirely devoted to study aspects related to packet transmission via satellite. The main objectives of COST Action 272 were the identification of key requirements, analysis, performance comparison, architectural design and protocol specification of packet-oriented satellite communication systems, with a clear focus on Internet-type system concepts, applications and protocols/techniques across the various layers. This Action firstly assessed the interesting satellite-specific market segments and came up with a clearly focused set of reference scenarios (global/regional, GEO/non-GEO, broadcast/multicast/interactive, QoS/best-effort, all-IP/hybrid, etc.) as a basis for further research and development work, also providing some interesting technical solutions. COST Action 272 was the continuation of COST Action 253 ("Service Efficient Network Interconnection via Satellite") [65] and the starting point for the SatNEx Consortium, which elaborated the SatNEx NoE proposal.

2.6.7 The ISI Initiative

http://www.isi-initiative.eu.org/

The *Integral Satcom Initiative* (ISI) is an open platform, started in 2005, whose membership embraces all relevant and interested private and public stakeholders. ISI collaborates and cooperates with the European Commission, the *European Space Agency* (ESA), the EU and ESA Member States and Associated States, the National Space Agencies, International Organizations, user Fora, and other European technology platforms. ISI fosters international cooperation under a global perspective. The ISI technology platform brings together for the first time in a unified, industry-led forum all research and technology aspects related to satellite communications, including mobile, broadband, and broadcasting applications. The purpose is to foster and develop the entire industrial sector, to maximize the value of European research and technology development, and to contribute to EU and ESA policies. The document in [66] specifies the *Strategic Research Agenda* of the ISI technology platform. It addresses the overall development of satellite communications and satellite broadcasting in Europe till about year 2020. In doing so, it shows that satellite communications and broadcasting has strategic relevance for Europe, and identifies medium and long term strategic objectives. Key research themes of ISI are cited in [66]; among them, RRM research topics are addressed in various points of the ISI research vision. In particular: (*i*) cross-layer design of RRM techniques, with cross-layer information coming from adaptive physical layer and QoS requirements from upper layers, to achieve optimum performance of mobile broadband multimedia satellite services, is one of the key research items; (*ii*) advanced RRM techniques can provide optimum use of the scarce spectrum resource and contribute to lowering the level of electromagnetic radiation in the hybrid terrestrial/satellite network environment; (*iii*) novel RRM protocols are considered, which include *Medium Access Control* (MAC) and *Usage Parameter Control* (UPC) mechanisms for the QoS provision under fairness constraints.

2.7 Conclusions

The goal of RRM is to optimize capacity utilization and QoS in satellite links, in the presence of traffic flows generated by services with different requirements. The best results are obtained with the cooperation of the protocols operating at different architectural layers, i.e., through a cross-layer approach, while maintaining the principle of layer separation. A possible grouping of the RRM techniques in the literature can be: frequency/time/space resource allocation schemes, power allocation and control schemes, and call admission control and handover algorithms. For each of these groups, this Chapter reviews the current results in the literature, even if the survey is far from being exhaustive.

Some ongoing research projects in Europe that consider the RRM problem are cited, and the reader is encouraged to visit their Web sites for further information. Among these projects, the SatNEx Network of Excellence deserves special attention. It combines the research activities of 22 European institutions, with proved excellence in satellite communications. The realization of this book has been made possible due to the SatNEx support.

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