Engineering the satellite component of a hybrid satellite-terrestrial system for MBMS delivery

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Abstract—**The synergy between satellite and terrestrial mobile networks is regarded as a promising approach for the delivery of broadcast and multicast services to mobile users. This paper evolves around a hybrid satellite-terrestrial system, featuring a unidirectional satellite component that is responsible for the delivery of point-to-multipoint services. It proposes a systematic approach for the satellite system capacity partitioning between streaming and push-and-store services and the radio bearer configuration within the satellite access layer. The approach takes into account the service requirements, estimates of the traffic demand and popularity of individual services and preliminary link dimensioning exercises. A capacity analysis is carried out in the end to check the efficiency of the approach, concluding in the same time on the feasibility of this hybrid system solution.**

Keywords-component; MBMS, S-UMTS, streaming, broadcast scheduling, UTRA FDD interface

I. INTRODUCTION

The introduction of broadcast and multicast modes of service delivery in terrestrial mobile networks is one way to address concerns regarding the additional traffic load generated by bandwidth-demanding multimedia services. The ongoing standardization work within the 3GPP MBMS (Multimedia Broadcast Multicast Services) framework is moving along this direction [1]. More drastic approaches rely on synergies between 3G networks and broadcast systems. This paper evolves around a hybrid terrestrial-satellite system that uses a geostationary satellite component for MBMS delivery.

The satellite component of the system is unidirectional, namely there is no satellite return link. A return path is rather provided via the terrestrial mobile network calling for a higher integration between the terrestrial and the satellite system components. Central to the system concept is the use of terrestrial gap-fillers, hereafter identified as *intermediate module repeaters* (IMR). The introduction of IMRs in the system architecture has been deemed mandatory in order to overcome the inability of mobile satellite systems to provide adequate urban and indoor coverage. With this additional feature, the handheld mobile terminal receives data through the satellite and/or the intermediate module that features one-way repeater functionality. The satellite path would be the preferred communication link (direct access-DA), but if the user's satellite path were blocked, the communication link would be sustained via the IMR stations (indirect access-IDA). The introduction of IMRs provides significant power gains, which are however to be weighted up along with the intrinsic generation of *artificial multipath*.

We focus subsequently on the long-term radio resource management (RRM) functions related to the satellite component of the hybrid system. Firstly, we briefly describe the reference Wideband CDMA (WCDMA)-based access scheme, engineered within the European IST SATIN project[1] [2] as an adaptation of the 3GPP UMTS Terrestrial Radio Access (UTRA) Frequency Division Duplex (FDD) air interface [3]. The two service categories –or, better, service delivery modes– supported by the system, namely streaming and push and store (download) services, are subsequently outlined and a rough methodology for the derivation of the system-level traffic demand for streaming services is described in section III. The estimated traffic demand is then used for the computation of the radio resources required for streaming services in section IV. Remaining resources are then available for the support of push & store services. The amount of push & store content that can be supported is estimated in section V as a function of its type, size and relative popularity. Finally, a capacity analysis is presented in section VI reporting the aggregate rates than can be supported in the system, under three different assumptions for the radio propagation conditions.

II. SATELLITE RADIO INTERFACE AND RADIO RESOURCE MANAGEMENT CONSIDERATIONS

The satellite radio interface design targets maximum commonalties with the FDD mode of the T-UMTS air interface. Fig. 1 shows the channels that were retained in the satellite radio access scheme design along with their mapping through the scheme layers/sub-layers. The channels of the satellite access scheme effectively form a subset of the full channel set of UTRA FDD. In particular, given the point-to-multipoint (p-t-mp) nature of supported services, this subset includes only common channels.

For the multimedia data transport, there is one-to-one correspondence between service and logical channel (common traffic channel - CTCH[2]). The logical channels are then

[1] The IST SATIN project, www.ist-satin.org, is partly funded by the European Union under its 5th research framework program.

[2] Work progress within the 3GPP MBMS framework [4] suggests that a new logical channel will be introduced into the UMTS standard

mapped, again in one-to-one mode, to the forward access channel (FACH). At the physical level, secondary common control channels (S-CCPCHs) carry (multiplex) one or more FACHs. S-CCPCHs are fixed spreading factor channels making use of the full spreading factor range reported in 3GPP standards (4-256). We refer the interested reader to [2] for a more detailed description of the satellite radio interface layers at both the data-plane and the signalling plane, while we devote the rest of this section to some RRM considerations.

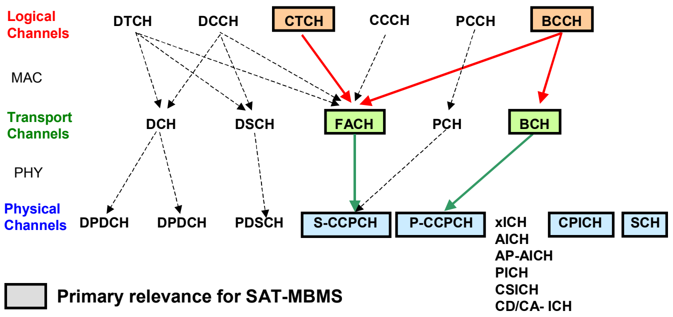

Figure 1. The mapping of channels within the SATIN radio interface

The satellite component of the hybrid system is primarily oriented towards *streaming* (e.g. audio, video broadcasting, alert and emergency announcements) and *push & store* applications (e.g. infotainment, entertainment, software delivery, web-casting). In fact, streaming and push & store should be seen as service delivery mechanisms. The same content may reach the mobile user in either of the two modes: in the first case the multimedia content can be played directly upon reception at the user terminal, whereas in the second case the multimedia content is stored in a local cache for later processing (*pre-stored content*).

On the other hand, the absence of return link means that the satellite radio access network cannot have real time feedback from the groups (e.g. user-side measurements), directly restricting the system short-term RRM functions: no fast power-control is feasible and the packet scheduler decides on its allocations without knowledge of the state of individual channels; what is called channel state dependent scheduling is not possible. In both cases, even if a return satellite link were available, the user feedback would have to be exploited in non-standard manner due to the point-to-multipoint nature of the services.

Both factors, the p-t-mp service nature and the unidirectional system, increase the importance of the longer-term RRM functions of the system satellite component. The approach we describe for the configuration of the satellite radio interface resembles dimensioning procedures well known from terrestrial wired networks. It relies on prediction of traffic demand for real-time streaming traffic that is expected over subsequent time intervals, which may be based on historical data drawn from measurements. This is then exploited to derive a static radio bearer (RB) configuration over some interval of time, over which the traffic mix remains the same. The remaining capacity is used for the transmission of push & store services.

for the support of MBMS, called Multicast Common Traffic Channel (MTCH). The discussion in the paper applies equally to this new channel, at least regarding the data transfer functions.

III. TRAFFIC ESTIMATION FOR STREAMING SERVICES

The estimation of traffic demand for multicast/broadcast services proved to be particularly challenging for two main reasons:

- The services under consideration are point-to-multipoint, hence the system requirements cannot be derived via a straightforward multiplication of the user requirements times number of subscribers, which is the standard practice in unicast systems.
- There is lack of historical data on the demand for a number of services (i.e. streaming) and the usage patterns related to it. This lack is not specific to satellite or, in general, wireless networks. The relevant literature is poor even in the context of wired networks.

The characterisation of the services has been differentiated for the two main types of services, i.e. real-time data streaming services and push & store services (TABLE I. Streaming service flows are characterised in terms of the attributes in [5] such as guaranteed rate, maximum rate, SDU error rate, packet size etc. On the other hand, in the case of push & store services, there is no inherent guaranteed or peak rate. Individual items within each service category are characterized by their size and the aggregate user demand for them. For these services the actual rate will be determined when deriving the broadcast schedules (see section V).

The methodology for the derivation of the traffic demand for streaming services in described in detail in [6] and it is summarized in [2]. Two different user profiles have been considered corresponding to a typical and business user behaviour. Traffic mix scenarios were built for two busy hours of the day, corresponding to dominant contribution by the business and the typical user respectively. Four traffic mixes have been derived by considering the system at two different instants of its life, corresponding to different subscriber volumes. In the following we maintain the first traffic mix (hereafter called traffic mix 1) for demonstration purposes [2].

This traffic mix is input to the dimensioning procedure to provide the radio bearer configuration in the satellite radio interface.

TABLE I. SERVICES CONSIDERED AND THEIR TRAFFIC HANDLING PRIORITY ACCORDING TO [5]

Service category	UMTS QOS class	Service type	Traffic handling priority
Streaming services	Streaming	Audio Streaming	1
	Streaming	Video Streaming	1
	Interactive	Location Based Services	2
Push & Store services	Background	Webcasting	Normal
		Rich audio/video info	High
		Pre-stored movie on demand	Low
		Pre-stored video on demand	Low
		Pre-stored radio on demand	Low
		Pre-stored music on demand	Low
		Software download	Normal

IV. RADIO BEARER CONFIGURATION FOR STREAMING SERVICES

The assumption is that there is some minimum characterisation of individual services in terms of arrival rate λ_i, duration μ_i and requested rate for each type of service R_i. This task allows the configuration of the bearers such as the number of FACHs, rates and mapping to S-CCPCHs. It may be split into more than one step, whose actual context depends on the assumptions about the available service characterization.

A. Estimation of required CTCHs/FACHs

Let S be the set of different services. A service flow is characterised by the 3-tuple $\{\lambda_i, \mu_i, R_i\}$; in this context, audio broadcast at 32 kbps is regarded as a different service than audio broadcast at 64kbps. The cardinality of the service set is N, i.e. $|S|=N$. No assumption is made for the flow burstiness; the flow might be of constant or variable bit rate but in the latter case the R_i value is set to the mean/guaranteed rate attribute. Each element S_i corresponds to a member of the service set, i.e. a service. Let P_{bl} a vector of size N corresponding to blocking probabilities targeted for each service, i.e. there is one-to-one correspondence between s_i and P_{bl}^i. Then the required FACHs for each s_i can be derived via use of well-known results of classical queuing theory:

- From the m-server loss queueing system (see, for example [7]), for each service type S_i separately. This implies invocation of the M/M/m/m formula N times.
- From the extension of the Erlangian formula to the multiple services scenario over all types of flows s_i requesting the same rate R_i, irrespective of the arrival rates or service durations of the individual services. The respective formula (see e.g. [8]) is applicable under the complete-sharing (CS) assumption: FACHs can be fully shared among services requesting the same rates, as long as the derived Transport Format Combination Set (TFCS) can cope with possible discrepancies at the packet level.

In both cases the required number of FACHs is the number of servers of rate R_i that will guarantee the target blocking probabilities P_{bl}^i. The outcome of this step for traffic mix 1 is given in table II.

TABLE II. REQUIRED FACHS FOR TRAFFIC MIX 1 (TARGET GOS 1%)

FACH rate	16kbps	32kbps	64kbps	128kbps	256kbps
# of FACHs	8	4	5	3	2

B. Mapping of the FACHs on S-CCPCHs

The objective of this function is to map the FACHs estimated in IV.A to the available S-CCPCHs. The number of available S-CCPCHs M and their maximum capacity c, or a rough estimation of theirs, are known a priori from link budget exercises and link-level simulation input. The link budgets for the indirect case dictated a maximum supported bit rate of 384kbps, corresponding to SF 8. Allowing codes for the broadcast channel and the announcement channel, the available S-CCPCHs at SF 8 are 6-7. In the following demonstrations, we assume the availability of 6 S-CCPCHs of SF 8.

There are two alternatives for this mapping:

One is to ignore the power requirements (E_b/N_o) of individual services. Then a mathematical formulation of the problem could be:

$$\text{minimize} \quad z = \sum_{j=1}^{N} y_j$$

$$\text{subject to} \quad \sum_{i=`}^{N} R_i x_{ij} \le c y_j\,,\ j \in \{1..N\} \qquad (1)$$

$$\sum_{j=1}^{N} x_{ij} = 1\,,\ i \in \{1..N\}$$

where y_{ij} = 1 if S-CCPCH j is used or 0 otherwise and x_{ij} = 1, if service (FACH) i is assigned to S-CCPCH j, 0 otherwise. This is the bin-packing problem [10]: the FACHs are the items that have to be packed into the minimum possible number of bins, corresponding to S-CCPCHs. A feasible solution of the problem corresponds to cost values z less than or equal to M. Both approximate and exact algorithms are available for the solution of this problem; given the rather small number of S-CCPCHs, computation efficiency does not pose significant constraints

The second option is to take into consideration the power requirements (E_b/N_o) of the individual services into what we call *power-aware packing*. In this type of service packing we apply a variation of the bin-packing algorithm to derive a mapping that minimizes the power waste, in that it allocates services of similar power requirements to each S-CCPCH. The E_b/N_o requirement is a function of the Transport Block (TB) size most frequently used.

In comparison with (1), only the objective function changes:

$$\text{minimize} \quad z = \sum_{j=1}^{N} y_j \cdot (E_b/N_o)_j\,,\ j \in \{1..N\})$$

$$\text{where} \quad (E_b/N_o)_j = \max_k \{(E_b/N_o)_k, k : x_{kj} = 1\}$$

Although the objective function in this case is non-linear and less conventional, adaptations of the approximate algorithms for the classical bin-packing problem [10] can be used to obtain an approximate solution of the problem.

The mappings for the two alternatives described above are given in Table VI. As expected, the power-aware mapping tends to bring together on the same code channel services of similar performance at the physical layer.

C. Derivation of the per S-CCPCH TFCS

Strict rules or algorithms for this task are difficult to devise. In any case, deriving the TFCS a priori on the basis of traffic predictions is not too efficient. The TFCS should be broad enough to capture the packet-level dynamics of the services expected over some future time interval. The wider the range of services, the broader the TFCS should be with direct impact on the terminal processing requirements.

The chosen Transport Block (TB) sizes should be in line with the packet sizes expected from the applications, so that framing overheads in terms of headers and padding are minimum.

TABLE III. MAPPINGS FOR TRAFFIC MIX 1: BIN-PACKING (LEFT) AND POWER-AWARE PACKING (RIGHT)

	Bin packing						Power-aware packing					
S-CCPCH	**1**	**2**	**3**	**4**	**5**	**6**	**1-2**	**3**	**4**	**5**	**6**	**7**
SF	**8**	**8**	**8**	**8**	**8**	**8**	**16**	**16**	**16**	**8**	**8**	**8**
Streaming FACHs (number x kbps)	1x256 1x32 1x16	1x256 1x32 1x16	2x128 1x32 1x16	1x128 2x64 1x16	2x64 2x16	1x64 1x32 2x16	1x32, 4x16	1x64, 2x32	2x64	1x128, 2x64	2x128	1x256
Streaming Sum	304	304	304	272	160	128	96	128	128	256	256	256
Push & Store FACHs (number x kbps)				1x32	1x144	1x176	1x48	1x20	1x20	1x48	1x48	1x52

The same reasons, namely the minimization of the overheads and the resource utilization efficiency, dictate Transport Formats (TFs) for each FACH that can cover the full range of short-term rate variations.

V. DIMENSIONING FOR PUSH & STORE SERVICES

System capacity not required for streaming services is used for the delivery of push-and-store services. This is the residual capacity after deriving the FACH requirements for streaming services and is organized into FACHs carrying *broadcast schedules*.

Each broadcast schedule carries several *items* of various content types such as compressed HTML pages, audio files, video clips, and software packages. The requirement for these services is the design of efficient broadcast schedules that, in combination with cache management algorithms at the terminal side, minimize the average *response time*. This is defined as the time elapsing from the moment a user expresses his/her will to receive some content up to the moment the content is stored at his/her terminal, averaged over all items. The design of optimum broadcast schedules considers the number and sizes of the individual items and their demand probabilities. The more popular a certain item is, the more frequently it appears within the broadcast cycle over the air.

Apparently the design of broadcast schedules targeting different response times is a way to support service differentiation for push and store services. The maximum number of items that can be accommodated on a broadcast schedule as a function of the capacity of the FACH channel that will deliver them, for different target response times, is estimated on the basis of the bounds provided in [11] for items, of different length distributions and demand probabilities. In this sense, it is an upper bound. On the other hand, the use of intelligent cache management techniques at the terminal side can reduce (resp. increase) the response time bounds (the number of supported items for a given bound) significantly.

TABLE IV. DIMENSIONING OF BROADCAST SCHEDULES FOR RICH AUDIO/VIDEO MESSAGES

FACH capacity (kbps)	Target response time (mins)					
	1	*2*	*3*	*5*	*10*	*15*
32	8	17	28	49	110	175
144	44	97	155	278	614	973
176	55	121	195	350	772	1221

TABLE V. DIMENSIONING OF BROADCAST SCHEDULES FOR WEBCAST AND SOFTWARE DOWNLOAD

FACH capacity (kbps)	Target response time (mins)				
	5	*10*	*15*	*20*	*30*
32	9	18	28	38	61
144	44	98	155	220	355
176	55	124	199	277	447

We introduced three priority classes for the push & store services –high, normal and low. The supported number of items is reported in table IV and table V as a function of both the FACH capacity and the target response time. The demand probability of the items follows the Zipf distribution [12] with smaller items being more popular than larger ones.

VI. CAPACITY EVALUATION

In order to provide evidence for the feasibility of the proposed system approach, a capacity analysis has been carried out.

First, the computation of the available $E_C/(N_0+I_0)$ has been undertaken for both DA and IDA cases (section II); secondly, considering the five traffic mix scenarios along with the two separate mapping strategies (section IV.B), the $E_C/(N_0+I_0)$ required to achieve a BER of 10^{-6} (i.e., BLER approximately 10^{-3}) for all the transport channels is computed. The following assumptions have been made:

- 20% of the link power is dedicated to pilot channels
- signalling is provided by means of a 8 kbps channel with SF equal to 256, which corresponds to a worst case performance in terms of required BER, because of the limited efficiency of the turbo code internal interleaver for short packet lengths;
- rate 1/3 turbo coding is considered for both data and signalling, along with QPSK modulation.

TABLE VI. reports the link budget analysis and the available data plus signalling $E_C/(N_0+I_0)$. Notably, thanks to the IMR power amplification, the received power in the IDA case is larger than that achievable in the DA case, confirming the efficiency of the IMR layout. On the basis of these data, the results reported in table VII have been obtained; results are shown for all five traffic mixes considered and for the two mapping strategies.

TABLE VI. LINK BUDGET PARAMETERS FOR BOTH THE DIRECT AND THE INDIRECT (THROUGH IMR) LINK

	DA	IDA		DA	IDA
Frequency of operation (GHz)	2.5	2.5	Chip rate (Mchip/s)	3.84	3.84
Polarisation + Pointing Losses (dB)	1	1	Terminal Antenna Gain (dBi)	2	2
Thermal Noise Density (dBW/Hz)	-204	-202.6	Received Power (dBW)	-134.5	-131
Data + Signalling $Ec/(N_0+I_0)$ (dB)	1.5	3.89	**Overall $Ec/(N_0+I_0)$ (dB)**	**2.47**	**4.86**
SAT/ IMR EIRP/ traffic code (dBW)	57	-19	Interference Density (dBW/Hz)	-209	-209
Free Space Losses @ 20° elevation or Path Loss (d = 346 m), ETSI model (dB)				192.5	113

TABLE VII. CAPACITY ANALYSIS FOR THE CONSIDERED L2 TRAFFIC MIXES

Traffic Mix	*Aggregate Bit Rate -kb/s*	**Ec/(No+Io) (dB)**								
		AWGN Channel			**Ricean Channel**			**IMR Multipath Channel**		
		Required Mapping		***Available***	***Required Mapping***		***Available***	***Required Mapping***		***Available***
		Bin	***Power***		***Bin***	***Power***		***Bin***	***Power***	
1	1472	-0.86	-1.52	1.5	1.42	0.83	1.5	-3.17	-3.22	3.89
2	1424	-0.86	-1.53		1.42	0.83		-3.17	-3.24	
3	1344	-1.45	-1.64		1.16	0.76		-3.17	-3.22	
4	1600	-	-1.45		-	1.01		-	-3.20	
5	1680	-	-1.20		-	1.17		-	-3.18	

Notably, the very satisfying results obtained in the multipath IMR case, with margins larger than 7 dB, are obtained by considering ideal combining. In actual conditions non-negligible performance deterioration is expected that, however, is completely acceptable due to the large power margin.

It is worthwhile concluding by observing that this study demonstrates the feasibility of the satellite Broadcast/Multicast overlay network approach proposed paving the way for its future development. The studies performed show in fact that the link budget can be closed with both the DA and the IDA scenarios achieving aggregate bit rates up to 1680 kbps.

VII. CONCLUSIONS

The paper presents a systematic approach for engineering the satellite radio interface of a hybrid satellite-terrestrial system. Both the unidirectional nature of the system and the particular service offering (point-to-multipoint services) favour more static approaches to its configuration and dimensioning.

We describe a top-down approach that has as a starting point the description of per-user traffic demand and leads to the derivation of the radio bearer configuration for streaming and push-and-store services in the satellite radio interface. The approach is generic in that it considers both service-delivery mechanisms and their requirements in terms of Grade/Quality of Service. An operator might include only one service type in his offering and/or relax their GoS/QoS requirements.

The critical point of this approach has to do with the input information for the traffic demand estimation for point-to-multipoint services. Few data are available on point-to-multipoint services, not only with regard to satellite communication systems but also in the more generic context of data networking. We argue that this is one of the directions that should attract the interest and efforts of the satellite research community in the future so that approaches such as the one described in this paper can be used with confidence in the engineering of multicast/broadcast satellite systems.

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REFERENCES

[1] 3GPP TS 23.246, "Multimedia Broadcast/Multicast Service; architecture and functional description," Release 6, September 2003

[2] K. Narenthiran *et al*., "S-UMTS access network for MBMS service delivery: the SATIN approach," International Journal of Satellite Communications and Networking, January-February 2004

[3] H. Holma and A. Toskala (Eds), WCDMA for UMTS, John Wiley and Sons, second edition, 2002

[4] 3GPP TS 25.346, .Introduction of Multicast broadcast service (MBMS) in the Radio Access Network", v1.61, May 2003

[5] 3GPP TS 23.107, "QoS concept and architecture," Release 5, v.5.11, December 2003

[6] IST SATIN consortium, " Simulation results and evaluation," IST Satin project deliverable no. 7

[7] D. Gross and R. Harris, Fundamentals of queueing theory, 2nd edition, John Wiley and Sons, 1985

[8] J. Kaufman, "Blocking in a shared resource environment," IEEE Transactions on Communications, Vol. COM-29, October 1981

[9] G. Albertazzi, W. De Win, N. Dimitriou, M. Neri, P. Salmi, and M.A.K. Sumanasena, "On the physical layer for satellite multicasting/broadcasting services," in Proceedings of IST Mobile & Wireless Communications Summit 2003, Aveiro, Portugal, June 2003

[10] S. Martelo and P. Toth, Knapsack problems: Algorithms and computer implementations, Wiley & Sons, 1990

[11] N. Vaidya and S. Hameed, "Scheduling Data Broadcast in Asymmetric Communication Environments," Wireless Networks, vol. 5, no. 3, pp. 171-182, May 1999

[12] G.K. Zipf, Human behavior and the principle of least effort, Reading, MA, Addison-Wesley, 1949