AROMA White Paper

Overview of Economic Evaluation of Novel AROMA RRM/CRRM Algorithms and Solutions

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Abstract

This paper provides an overview of the main results coming from the techno-economics investigations carried out by the IST AROMA[1] project [1] (www.aroma-ist.upc.edu). Aims of these activities were to highlight economic impacts of the Radio Resource Management (RRM) and Common RRM (CRRM) mechanisms within the context of an all IP heterogeneous network as well as to investigate the potential benefits coming from the long-term evolution of the existing mobile network architecture towards a new architecture based on the all IP paradigm.
After giving some general information related to the methodology followed for the techno-economic evaluations, a couple of relevant study cases is presented:

- the first one dealing with a selected CRRM algorithm based on a “fittingness factor” (it is a particular metric that helps in selecting the most suitable RAT/cell to be used in a heterogeneous scenario), whereas
- the second one is related to the mobile TV over MBMS versus HSDPA.

In both the case studies, the techno-economic evaluations have been carried out by assuming a short or medium term increase of data traffic and by analyzing the potential savings offered by the addressed solutions with respect to the total investment (CAPEX+OPEX) needed to increase the capacity of a pre-existing network.
Results of the study summarized hereby can be found with greater details in deliverable D17 [2] developed within AROMA WP2, where techno-economic analyses and evaluation of the technical outputs of the project are performed.

1 AROMA PROJECT OBJECTIVES SUMMARY

Results achieved by the AROMA project were devoted to asses and maximize the potential benefits coming from the medium-term evolution of the addressed radio access technologies (e.g. GSM, UMTS, HSPA, MBMS, WLAN, etc) by means of the most promising and advanced RRM and CRRM mechanisms. Within this context, results provided by the project deal not only with the technical aspects but also with the potential impacts of these solutions from a techno-economic point of view.
In general term, mobile communications will continue to be one of the most dynamic and profitable market sectors in current and future economics, although it is also one of the most high demanding economic sectors from the point of view of the required investments. In such a competitive and standard-centric industrial environment, the economic exploitation of the solutions directed towards the optimization of the network performance is of key importance. For this reason, it was considered fundamental for the AROMA project to have the opportunity to carry out techno-economic analyses and evaluations of the technical issues addressed by the project, investigating also the business impacts and the return of investments (ROE) of these solutions.

[1] Acronym of the FP6 IST STREP project entitled “Advanced Resource Management Solutions for Future all IP Heterogeneous Mobile radio environments”, started in January 2006.

More in detail, objectives of the techno-economics investigations have been:

- To demonstrate the economic benefits of the proposed algorithms and techniques (complementing the technical evaluations carried out by the project)
- To give evidence of the potential economic advantages of using the specific RRM/CRRM algorithms addressed by AROMA project
- To identify and evaluate economic drivers in terms of CAPEX (CAPital EXpenditure) and OPEX (OPerational EXpenditure) to migrate and converge towards an all IP heterogeneous architecture
- To identify the most relevant economic scenarios, hypothesis and parameters dealing with RRM/CRRM solutions.

In order to accomplish the techno-economic evaluations, CAPEX and OPEX figures have been collected from public available sources (mainly [3],[4], [14]) and further elaborated internally by the AROMA consortium.
The paper is arranged as follows: Section 2 describes the general methodology followed in all the techno-economics evaluations. Section 3 reports the techno-economic evaluation of mobile TV service over MBMS and, finally, Section 4 reports the techno-economic evaluation of a CRRM algorithm between GSM and UMTS based on the Fitness Factor framework developed within the AROMA project.

2 METHODOLOGY

2.1 Investments versus revenues valorization

All the techno-economic evaluations have been carried out by assuming a short- or medium- term increase of the data traffic and by analyzing the potential savings offered by the addressed solutions with respect to the total investment (i.e. CAPEX and OPEX) needed to increase the capacity of the network. Hence, following the same approach also described in [4], these evaluations are based only on the estimation of the total costs faced by a network operator for upgrading the already deployed network in order to support the expected amount of traffic.
In principle, an alternative way of calculating the economic value of the solutions taken into account could be based also on the estimation of the extra revenues related to the additional data traffic supported by the network. This approach has been considered less appropriate since it would require as much exact as possible assumptions on the revenues deriving from the services. Unfortunately, market forecasts on revenues could be very subjective and are usually affected by an higher degree of uncertainty with respect to the estimation of the network investments, since these are strictly related to the willingness to pay of the users for new services. Moreover, revenues from the offerings of new services are strictly dependent also on specific marketing strategies carried out as far as the end-user pricing policies are concerned, which can find justifications on many reasons (e.g. promotion of a specific new service by means of flat-rate prices, volume discounts to boost the service usage, etc.). As a consequence, service revenues are not always proportional to the load generated in the network, because these ones responds to different (marketing based) mechanisms with respect to the technical ones. Thus, the value of the service can be not related at all to the traffic generated. For this reason the revenues typically do not grow linearly with the amount of data exchanged, and this make hard to estimate the economic impacts of the addressed solutions on the basis of the capacity increase achieved within the heterogeneous network.

2.2 Dependence of the results from the time based traffic hypotheses

The carried out techno-economic investigations are based on the assumptions that a not negligible increase of data traffic will be demanded by users of mobile heterogeneous network in the next years, especially in dense populated areas. Several market forecasts agree on this assumption on the basis of the recent trends observed in European countries where 3G systems are more diffused nowadays. Even though the increase of data traffic demands is evident, it is however very difficult to say to what extent, and when, the potential savings related to this market trend can be realized. This uncertainty rise from the difficulty to make reliable traffic forecasts on a per year base, and thus it is difficult to say how big the demand for future network capacity will be.
In order to limit the sensitivity of the results on the traffic forecasts, the approach based on the comparison of the solution with respect a “reference case” has been followed. In this way, economic impacts have been highlighted according to a “what-if” approach, apart from the absolute values achieved. This means that the results reported in the next section should not be considered relevant in an absolute way but useful to compare the different scenarios taken into accounts.
In any case, it is worth noting that when the Net Present Value (NPV) of the investments during the reference period have been estimated , this calculus has been made in order to have a general idea of the actual economic value of the addressed solutions, even if should be clear that it strictly depends on the specific time assumptions considered.

2.3 Market penetration of multi-mode terminals

Another important aspect taken into account in the work consists in the thorough analysis of the market penetration of multi-mode terminals. How much relevant this aspect could be within the context of a heterogeneous network scenario is clear: by means of the CRRM mechanisms addressed by the AROMA project, different services are supposed to be offered by means of several radio access networks and technologies, in a transparent way for the users, with the aim of improving the QoS and optimizing the network. It is evident that this objective can be accomplished only if a no negligible percentage of users own terminals capable of using most of the radio technologies taken into account.
For the above mentioned reasons, as a starting point of the work, an in deep investigation concerning the actual mobile terminal penetration (differentiated with respect to the different technologies available nowadays) as well as the expected

short-term evolution of them has been carried out. On this concern the following information has been collected from public sources [5],[6],[7],[8],[9] and further elaborated for the specific scenarios taken as reference.
According to [6] Europe's operators estimate the UMTS adoption only by 10% of the European mobile users in 2007. This research also shows that UK and Italy are in the lead for 3G adoption: these countries are expected to see 3G penetration rates of 68% and 72%, respectively, by the end of 2010. Referring to [7], Figure 1 provides an assumed long-term growth rate for 3G penetrations up to 2021:

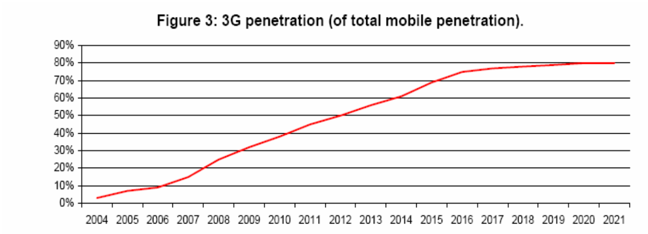

Figure 1 – Expected penetration of UMTS terminals up to 2021. [7]

With respect to the penetration of HSDPA capable terminal, as reported in [5] it is expected that about 19% of global mobile phone subscribers (40% of WCDMA connections) will have HSDPA capable terminals by 2011, ad depicted in Figure 2:

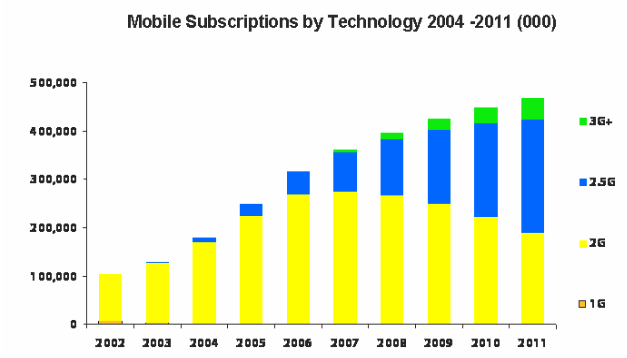

Figure 2 – Terminal penetrations vs. different technologies [5].

Also according to a white paper from the UMTS forum [9], by 2012, there will be almost 1 billion users of HSPA technology worldwide:

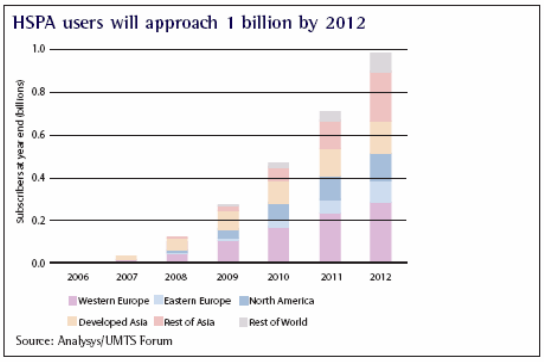

Figure 3 – Expected HSPA users worldwide (Source: UMTS forum [9]).

From the data reported above, we have derived the distribution of GSM, UMTS Release99 and UMTS HSDPA terminals that has been considered in the work, as shown by Table 5.

Table 1 - Forecast of distribution of GSM, UMTS R99 and UMTS-HSDPA terminals

YEAR	GSM terminals	UMTS R99 terminals	UMTS HSDPA terminals
2007	64 %	32.00 %	3.60 %
2008	57%	35.26 %	7.74 %
2009	48%	39.00 %	13.00 %
2010	38%	41.54 %	20.46 %
2011	35%	35.75 %	29.25 %
2012	33%	23.80 %	44.20 %

3 TECHNO-ECONOMIC EVALUATION OF MOBILE TV SERVICE OVER MBMS

3.1 Motivations

The choice of developing a business case focused on MBMS [10] depends on the fact that this technology, which is very promising from a commercial and evolutionary point of view, has also been widely studied in AROMA deliverables, and many different algorithms are based upon it.
A new kind of traffic generated by mobile TV subscribers is expected for the near future. Due to the characteristics of this service, the amount of data generated by these users can be significant and it impacts the capacity of the network.
Operators have multiple technology options to choose from to provide mobile TV and video services. Many of these options are either non available today or are currently being traded around the world. In this period before deployment of mobile broadcast or multicast networks, operators typically offer a streaming unicast/video download service or an early-stage mobile TV broadcast offering.
A mobile broadcast TV network, such as for example, a network based on DVB-H, is a separate network from a cellular one, so it will require a more significant infrastructure than providing either a multicast or streaming/unicast offering over a cellular network. That is the reason why operators will typically not make this investment alone, but either partner with a media company or lease the service from the mobile TV provider.
Moreover, most of the traffic for Mobile TV is generated by users which requires also voice and data services offered by means of UMTS network, mobile network operators have instead the opportunity to offer also the TV service by upgrading and improving the capacity of their UMTS networks, which is an alternative that may benefit from saving in investments and on a large scale basis economy.
The decision behind what type of broadcasting technologies can better fit Mobile Operator capacity needs and strategies also strongly depends on both regional regulatory constraints (standard and frequency band) and industry lobbies.
The main objective of the Mobile TV techno-economic analysis was to investigate the total investment (i.e. CAPEX and OPEX) needed to increase the capacity of the UMTS network in order to be able to support also the traffic generated by the expected Mobile TV service subscribers. As well-known the capacity of UMTS network can be effectively increased by means of the HSDPA technology. Even if HSDPA can be very useful to increase the network's capacity, in the case of Mobile TV, also the MBMS technology can be taken into account. MBMS has been defined just in order to use in efficient way the radio resources when the same content must be distributed among different users. For this reason the analysis has taken in consideration these two different technologies in order to see in which condition one of the two technologies may be considered more desirable with respect to the other (e.g. after how many years, under certain assumptions, MBMS may be considered more profitable than HSDPA to support Mobile TV subscribers, considering that in for MBMS it is necessary to reserve a fixed amount of the cell transmitted power).
In both cases, before assuming investments for the introduction of new nodeBs in the area of interest, it was assumed that the already existent nodeBs can be upgraded by activating a second UTRAN carrier in each cell.
On this concern, Figure 4 shows the logic modules of the evaluation model:

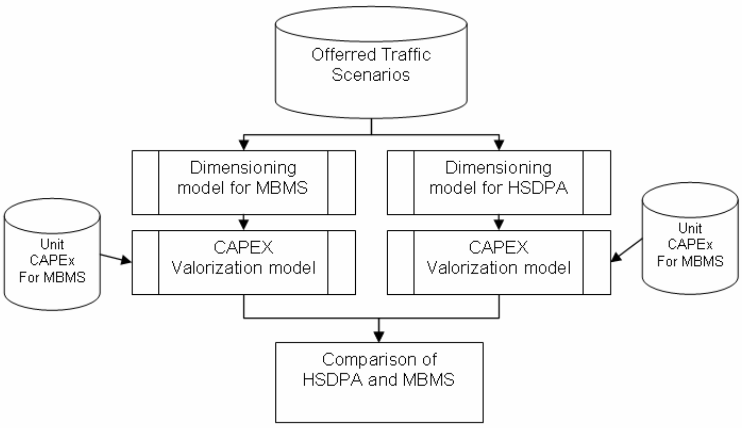

Figure 4 – Evaluation model for comparing Mobile TV over MBMS and HSDPA.

The analysis was made by taking into account a 10 year period starting from 2008 to 2018, because it is commonly accepted that the adoption of Mobile TV services will be gradual and not disruptive. For that reason the main economic results will be evident on a long-term scale, whereas in a short-term analysis, no meaningful outcomes may be pointed out.
In evaluating the investments which are needed for each solution, only the more expensive changes were considered. For example, the hardware and software upgrades costs relative to the introduction of HSDPA or MBMS are neglected because it is assumed that their order of magnitude is lower with respect to the planning of a second carrier or of new sites in order to serve the new traffic requirements. Moreover, these upgrades are commonly integrated in new versions of software (and hardware) for the network nodes, so that it's not possible to separate their cost from the general cost of a new software and/or hardware release comprising many add-on features.

3.2 Mobile TV traffic forecasts

Mobile TV traffic taken as reference comes from recent forecasts already available in the public domain [11]. The forecasts relating to the increase in Mobile TV use vary and they are typically unclear about which Mobile TV services they include. According to Strategy Analytics, by the end of 2006 there will be 8 million Mobile TV devices globally and by 2010 there will be 120 million Mobile TV service subscribers (3G 2006) [11]. Also IMS Research indicates that there will be 120 million Mobile TV service subscribers in 2010 (Wickham 2005) [11]. The number of Mobile TV broadcast service users is expected to grow from 130,000 in 2005 to 124.8 million in 2010 (McQueen and Reid 2005). The following table presents an estimation of European and worldwide Mobile TV users [11].

Table 2 - Mobile TV user forecasts (millions)

	2005	2006	2007	2008	2009	2010
Number of users in Europe	0 M	0.06M	0.33M	2.67M	11.15M	31.32M
Total number of users	0.13M	0.79M	3.09M	16.94M	52.38M	124.8M

It is worth noting that the methodology adopted to derive forecast data for Mobile TV users in the mentioned source only considers the users which effectively already own a terminal which is suitable for the fruition of Mobile TV service, so that MBMS or HSDPA penetration rates are already implicit and embedded in the considered figures. Forecasts shown in Table 2 were also extended to the following years of the analysis (up to 2018) by using a Bass diffusion model, which describes the process how new products get adopted as an interaction between users and potential users [12].
As regards to the customer behavior it is expected that the overall time spending on consuming media will be spread over different media platform both on fixed and access domain. Community, file sharing, peer to peer communications are some example of new ways of delivering and retrieving digital contents on fixed domain and it's not clear what will be the customer behavior on mobile domain. In the case of personal content such video on demand, Podcasting and Personal TV the unicast mobile technology will provide a good answer from technological point of view. In this scenario MBMS technology can provide Mobile Operators with a good flexibility in the managing and delivering mobile content in the case of traffic load in certain dense urban areas o in the case of peak traffic in certain time.
In the case of delivering media content with same paradigm of traditional analogical TV services, which means delivering 10-12 TV channels at the same time for a mass market, the broadcasting technology is the only ways of providing a satisfactory service. But also in this service scenario MBMS can play a role of complementary technology in order to deliver mobile content with a reduced duration in limited area or to target market segments such as Business TV. Each technology has its strengths. DVB-H and broadcasting technology handle a heavy usage of Mobile TV services with many TV channels broadcast all the time. Cellular technologies such as HSDPA and MBMS handle a low medium usage in a complementary way and for customer behavior more similar to what happens for Video Service on Internet domain.
The main disadvantage of broadcasting technology is that a Mobile Operator needs to deploy a more significant infrastructure investment. It's clear that the deployment of broadcasting technologies strongly depends on the market penetration of Mobile TV services as well as how long time each user watches Mobile TV on average.

3.3 Scenario

The forecast related to users growth [11], mixed with the usage of a mix of different services, determine the overall total annual traffic (for the whole country) which is represented in Table 3. Please note that the mix of services has already been grouped by taking into account the different requirements for each specific service, so that only four categories, the ones which are relevant for the dimensioning model, are considered. All the data related to Voice and Videotelephony services are expressed in Erlang, whereas both the Interactive and Background Data are expressed in terms of Mbps. Please note that we neglect the Uplink contribution for the Mobile TV service, assuming that it is non present at all or of an order of magnitude lower with respect to other services.

Table 3 – Global annual traffic for the whole country

Uplink Traffic	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL	UMTS UL
Voice (Erlang)	46,443	79,487	111,968	139,643	163,078	200,014	233,097	267,233	274,363	279,094	283,824	283,824
Videotelephony (Erlang)	7,422	12,703	17,894	22,317	26,063	31,966	37,253	42,708	43,848	44,604	45,360	45,360
Interactive (Mbps)	9	22	43	70	105	159	226	313	382	459	548	591
Background (Mbps)	9	22	43	70	105	159	226	313	382	459	548	591
HSDPA o MBMS												

Downlink Traffic	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL	UMTS DL
Voice (Erlang)	46,443	79,487	111,968	139,643	163,078	200,014	233,097	267,233	274,363	279,094	283,824	283,824
Videotelephony (Erlang)	7,422	12,703	17,894	22,317	418	31,966	37,253	42,708	43,848	44,604	45,360	45,360
Interactive (Mbps)	35	89	173	282	418	637	906	1,250	1,529	1,837	2,190	2,366
Background (Mbps)	35	89	173	282	418	637	906	1,250	1,529	1,837	2,190	2,366
HSDPA o MBMS	31	39	342	1,541	4,675	8,648	12,068	15,090	17,844	20,430	22,931	25,413

Starting form these traffic data for the whole country, in our analysis we decided to extend our business case to a single average town, having about one million inhabitants, which can be considered as a sort of prototype for an average industrialized European city. The distribution takes into account both the population of that town referred to the overall country population, and the area which must be covered in order to have a full coverage of the town.

The splitting of the town surface in dense urban, urban and rural areas has been put, for the sake of simplicity, equal to (respectively) nearly 20%, 40%, 40%, which represent reasonable figures for a typical town. The effective figures have been slightly changed in order to have a rounded number of sites for each area, respectively, 130, 20 and 1 site.

3.4 Technical approach and main results

Results of the techno-economic evaluation have been derived by applying a specific dimensioning model, described in [2]. Figure 5 and Figure 6 show respectively the total number of transceivers and of new cells required for each year to support the expected traffic, in the Mobile TV on HSDPA case.

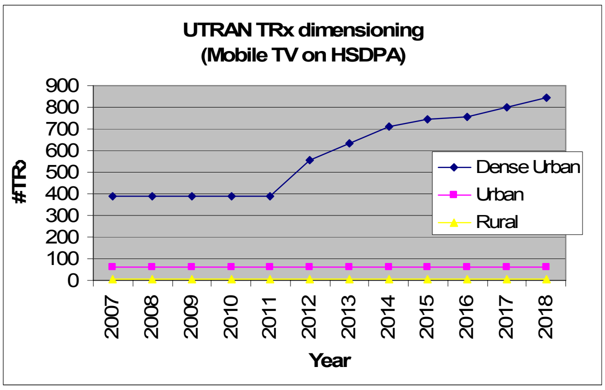

Figure 5 – Transceivers dimensioning (Mobile TV on HSDPA).

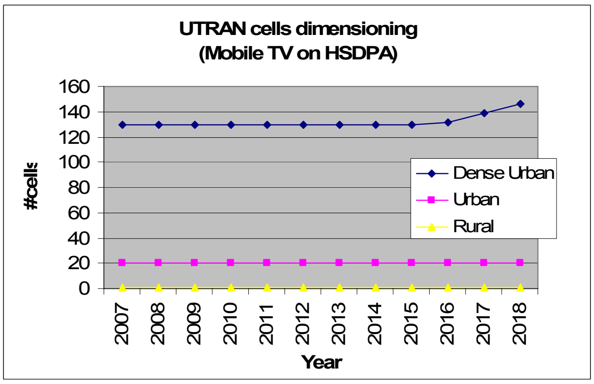

Figure 6 – UTRAN cells dimensioning (Mobile TV on HSDPA)

The investments related to the upgrade of HSDPA and MBMS technology where both neglected because their effective value is considered to be not relevant to the scope of our analysis which focuses on the advantages and disadvantages of the two technologies in order to fulfill the requirements due to a large and progressive extension of the Mobile TV service usage in an average town of a European country. In this scenario, the focus cannot be to make a real choice between two different technologies, from the operator point of view, because we can easily assume that both technologies will be by any means introduced by any European "big" mobile operator in the long term as a natural consequence of the common upgrading of their existing networks. In particular:

- The introduction of HSDPA (which consist both in hardware and software upgrades in different network nodes) is linked not only to the Mobile TV itself, but concerns the need of offering a quite wide range of data services, both interactive and background, directly connected to the supposed increasing usage of browsing and streaming applications. Many European operators have already or are quickly introducing HSDPA in their network as a natural upgrade of GPRS, so it is not difficult to suppose that HSDPA will be the rule for every mobile operator which offers a significant bouquet of data services, that definitely means every average mobile operator in the long term
- Also scouting of the solutions which different vendors, main players in the European market, put in their future roadmaps, shows that the changes related to the introduction of MBMS (mainly software updates in NodeBs, RNCs and in the Core Network), are considered as a software upgrade, which will be given in any case as a standard evolution of their RRM component.
- For similar reasons, we may assume that all the new equipment which must be added in the Core Network in order to connect with TV and video content sources, both proprietary or more likely belonging to a Media company linked with a partnership agreement, are an investment which is of a lower order of magnitude, which is probably the same for the two technologies, so that no differences are to be taken in consideration for the

single technology, and which will be by any means done, because it is needed for many different applications based on video and streaming fruition (not necessarily only for Mobile TV)

It is worth noting that, in order to make a fair comparison between HSDPA and MBMS, in the case study we assumed that HSDPA is used only for Mobile TV service. In a realistic case, it should be considered that HSDPA is also exploited to offer high data rate services to the users. In this sense, it should be expected that the capability to support Mobile TV users by means of HSDPA decreases when also other services are allocated on HSDPA and some QOS constrains have to be guaranteed for them. In this sense, the first year which requires additional transceivers using a second UTRAN carrier will of course anticipate with respect to our analysis (2011).
Concerning the number of sites, as shown in Figure 6, it keeps constant all over the period for Urban and Rural areas whereas in the Dense Urban Area we obtained a significant increase of sites only in the two last years.
In the case of Mobile TV on MBMS, achieved results show that all the traffic can be supported without introducing new site and only the introduction of new transceivers is required, as shown in Figure 7.

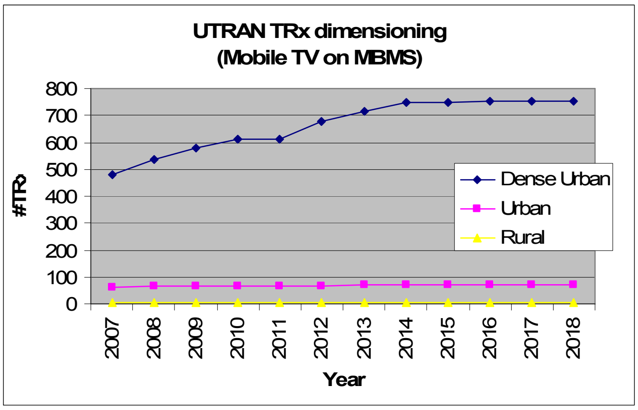

Figure 7 - UTRAN carriers dimensioning (Mobile TV on MBMS).

3.5 Conclusions

The cumulative CAPEX and OPEX for the two different technologies is compared in the following graph, which is relative to an estimation of the investments needed for an fictive average town in a European country, for a “main” mobile operator (e.g. incumbent or second operator, with a 40% market share).

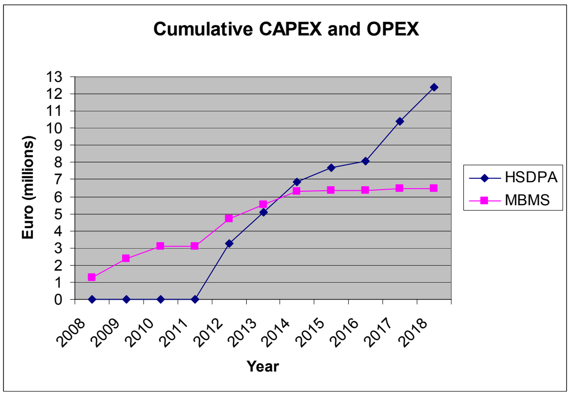

Figure 8 - Cumulative CAPEX and OPEX for MBMS and HSDPA

In the first years of the analysis MBMS is less convenient with respect to HSDPA because of the reasons already mentioned in previous section. When the number of Mobile TV subscribers continues to grow, the MBMS solution becomes more convenient. The break even point in our analysis is reached at around 2013. The number of users per cell (and their average usage) which is obtainable in this year may be considered the threshold of the data service usage that makes the introduction of MBMS more advantageous with respect to HSDPA. At the end of the observed period, the ratio of the cumulative investments for the two technologies is equal to 1.90, so the investments for supporting Mobile TV on HSDPA are nearly doubled with respect to the MBMS ones. In our analysis no new sites are added for MBMS solution, whereas their introduction is foreseen for HSDPA starting from 2016 (which corresponds to the knee of the curve of cumulative CAPEX and OPEX for this technology that can be observed in Figure 8. In any case, as already mentioned in section II, the achieved results strictly depend on the assumed hypotheses in terms of traffic, deployment and scenario.
Further details on this study can be found in AROMA deliverable D17 [2].

4 TECHNO-ECONOMIC EVALUATION OF FITTINGNESS FACTOR CRRM ALGORITHM

4.1 Motivations

Potential economic benefits of applying traffic steering policies between GSM and UMTS systems have been largely investigated within the context of the AROMA project. In the considered case study, the traffic steering strategy is supposed to be realized by means of a specific implementation of a RAT selection algorithm based on the Fittingness Factor framework. This framework has been developed by the AROMA project and assessed from a technical point of view in deliverable D12 of AROMA project [13].

The techno-economic evaluation has been carried out by assuming an increase of the data traffic demands for the next 5 years which requires new investments on network resources and by analyzing the potential savings offered by the CRRM algorithm with respect to the case when the algorithm is not present. In both these two cases (when the algorithm is present and when it is not), the specific investments considered in order to increase the capacity of the network to fulfill the traffic increase consists in the upgrade of the already present UTRAN sites by activating the second UTRAN carrier (i.e. same approach followed in [4]).

This choice can be understood by considering that, as it is well known, in WCDMA there is a limit over the capacity increase achievable by means of the introduction of new sites in a dense urban area. As a matter of fact, several UTRAN cells not so much spaced in a small area are not able to offer much higher capacity due to the mutual interference that every cell causes to each other.

On the other hand, in a capacity limited downlink scenario, it is evident that the additional frequency is able to offer a direct capacity increase[2]. As a results, in capacity limited urban areas adding more spectrums is a very cost efficient way to increase capacity whereas the alternative of increasing capacity by deploying new macro base stations is significantly more expensive.

4.2 Scenario and algorithm definition

The fictive scenario when the CRRM algorithm is supposed to operate consists in an already deployed 2G/3G heterogeneous network which offers the radio coverage in a specific area by means of GSM and UMTS co-site cells. Within this scenario, the following three main categories of mobile terminals diffused in the market nowadays are supposed:

- Category 1: single-mode"GSM-only" mobile terminals (i.e. 2G terminals)
- Category 2: dual-mode "GSM /UMTS-R99" mobile terminals (i.e. 3G terminals, not HSDPA capable)
- Category 3: multi-mode "GSM/UMTS-R99/HSDPA" mobile terminals (i.e. 3G terminals, HSDPA capable)

In the considered case study, it was assumed that subscribers having GSM terminals request only the voice service (neglecting the case of requests of data services over GPRS or EDGE, due to the fact that packet data services are provided in a best effort way on these technologies and this deals with no impacts on the voice capacity). On the other hand, 3G users are supposed to be able to request voice, video call as well as web browsing services.

When the CRRM algorithm is absent (reference case), the following prearranged camping strategy is performed by the network (this strategy corresponds to what most often happen nowadays in real network scenarios, where both 2G and 3G systems coexist in the same area):

- 2G terminals camp (obviously) on GSM system
- 3G terminals always camp on the UMTS system when a suitable UTRAN cell is available (from a radio quality point of view), so that they camp on GSM only in lack of 3G coverage conditions

Moreover, in the reference case it was assumed that users camped on UMTS which request the www services are always allocated on HSDPA, on condition that they own a HSDPA capable terminal[3]. Instead, video call service is always allocated on UMTS R99, since this real-time service requires a fix amount of bandwidth both in uplink and downlink. In the second case, when the CRRM algorithm is present, the selection of GSM, UTRAN dedicated transport channels or HSDPA is always performed in accordance of the fittingness factor values evaluated by the CRRM algorithm for each RAT, on the basis of the cell load of the cells.

According with the fittingness factor framework, the behavior of the CRRM algorithms depends (also) on the definition of the network-centric suitability $\delta(\eta_{NF})$ associated to each RAT, which represents a function that reduces the fittingness factor of the RAT depending on the amount of non-flexible load. The specific functions chosen for GSM, UMTS-R99 and HSDPA have been identified with the aim of implementing the following high-level load balancing strategy:

1. Voice calls are preferably allocated to GSM, when possible. Only when the GSM cell has no more radio resource available the user requesting voice is allocated in the UTRAN co-located cell, if available.
2. www connections are preferably allocated to HSDPA. Only when a high number of contemporary HSDPA users are present within a cell, the CRRM algorithm may select dedicated channels for allocating the new www request.

Advantages of the load balancing mechanism implemented by the CRRM algorithm on the basis of he two mentioned strategies have been investigated by evaluating year per year how many cells are no more able to support the assumed traffic so that they need to be upgraded with a second UTRAN carrier. Results demonstrate that when the CRRM algorithm is present, it is possible to have a smaller number of second carrier activations with respect to the reference case.

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2 Under certain conditions it is possible to see the additional carrier as being a parallel network. Limitations on the power amplifier means that the capacity gain could be lower than two, but it will still be significant.

3 This implies that all the UTRAN cells of the scenario are supposed to support HSDPA.

4.3 Technical approach and main results

A Markov based analytical model has been developed and exploited to derive technical indicators concerning the performance of the heterogeneous network with and without the presence of the load balancing mechanism implemented by the CRRM algorithm. The blocking probability experienced by the uses as well as the mean per user perceived throughput for the data service have been considered as key performance indicators (KPIs) of the network's performance. The above mentioned KPIs have been evaluated for all the 72 couples of 2G and 3G cells located in the area of interest, and per each of the 5 years taken into account.
KPIs mentioned above have been used to estimate how many cells cannot respect the QoS constrains specified in Table 4, due to an excessive amount of traffic offered by the users. In this way we derived the number of UTRAN second carriers that has to be considered in order to support the increase of data traffic during the five years.

Table 4: QoS constrains for a pair of co-located cells.

Performance	Threshold value
Voice loss	2%
Video loss	5%
Data loss	5%
HSDPA throughput	400 kbps
Data throughput	350 kbps

Results related to the number of UTRAN cells that should be upgraded by introducing the second UTRAN carrier, shown in Figure 9, demonstrate clearly the benefits of using the CRRM algorithm.

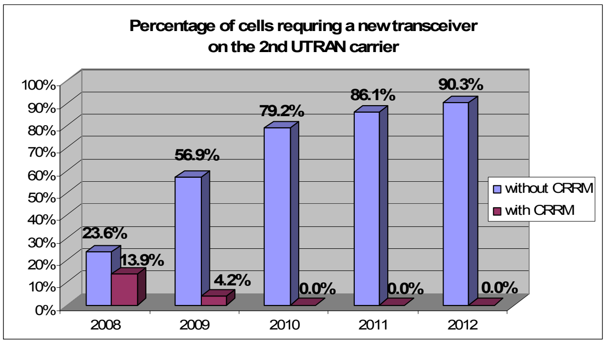

Figure 9 - Percentage of UTRAN cells which require the introduction of new transceivers on the 2nd carrier.

It is worth noting that, when the CRRM algorithm is used, the number of activations estimated by considering the QoS constrains decrease in the years following the first one. This issue can be understood by considering that the penetration of 3G terminals (as well as the penetration of HSDPA ones) increases during the time. For this reason, also the overall network performance increases due to the higher degrees of freedom of the CRRM algorithm. Even tough this phenomenon exists, it should be considered that in practice the investments related to the upgrade of UTRAN cells to introduce new transceivers using the second carrier are not alienable. This practical consideration has been taken into account in the estimation of the total investments, which has been done by considering that the investments related to the UTRAN cells required in the first year of the analysis cannot be recovered in the following years. In this sense, the number of second UTRAN carrier activations for the estimation of the investments is determined by the first year. Hence, the total investments (CAPEX + OPEX) needed to introduce the additional spectrum with and without the CRRM algorithm are depicted in Figure 10 (reference economic values have been taken from [3], [4], [14]):

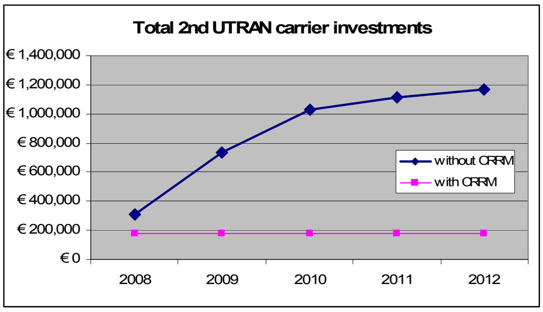

Figure 10 – Total investments needed to support the offered traffic with and without the CRRM algorithm.

Figure 10 clearly demonstrates the positive economic impacts offered by the CRRM algorithm in terms of investments savings. In any case, concerning this aspect, it is worth noting that the cost of the introduction of the algorithm has not been considered, since it is very difficult to estimate and it strictly depends on the specific implementations and technological choices which can be very different case by case.. In any case, also by considering that an extra cost should be included for the introduction of the CRRM algorithm, the economic benefits for an operator in terms of investments savings is not jeopardized.

Finally, Table 5 reports how the investments should be spread over the considered five years (note that with the CRRM algorithm, investments are needed only in the first year, in order to upgrade the ten most critical cells with the second UTRAN carrier).

Table 5 – Investments needed to introduce new transceivers on the 2nd UTRAN carrier (k€).

2nd UTRAN carrier investments (k€)	2008	2009	2010	2011	2012
without CRRM	306	432	288	90	54
with CRRM	180	0	0	0	0

By means of the figures reported in table above, it is possible also to estimate the Net Present Value[4] for the two considered cases, which represents the actual value of the entire investments made over the five years. NPV of investments without and with CRRM is about 1118 k€ and 176 k€ respectively, so that the difference in terms of NPV between the two considered cases (delta NPV) is about 942 k€ . This figure can be considered as the last key indicator of the positive economic impacts offered by the CRRM algorithm.

4.4 Conclusions

Achieved results clearly demonstrate the positive potential economic impacts of the introduction of the CRRM algorithm taken into account, in terms of investments savings. Even though a specific algorithm was taken as reference, the load balancing strategies implemented by the considered algorithm can be considered very general. For this reason, results similar to the ones reported in this work can be expected also with different CRRM algorithm implementations, on condition that they are devoted to put into practice the considered load balancing mechanisms. In this sense, the validity of the carried out techno-economic investigation can be considered quite general, too. It should be also considered that the economic analysis was based on the assumption that the network operator already has an important asset consisting in the already deployed GSM network. All the advantages offered by the CRRM algorithm is due to a better exploitation of this asset for voice users, which cannot be exploited adequately when 3G terminals are camped on UTRAN by default. In this sense, the validity of this analysis is limited to the case where the network operator has different radio access technologies and intends to put into practice appropriate strategies to exploit all of them within the context of an all-IP heterogeneous network. Finally, as already mentioned, the achieved results also strictly depend on the assumed hypotheses in terms of traffic, deployment and scenario. Further details on this study can be found in AROMA deliverable D17 [2]

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[4] A WACC of 2% is considered.

Bibliography

[1] F. Casadevall et al., “Overview of AROMA Project”, IST Mobile Communication Summit 2006.

[2] R. Farotto et al., “Economic evaluation of novel AROMA RRM/CRRM algorithms and solutions”, IST-AROMA Project, Deliverable D17, Oct. 2007

[3] K. Johansson, “Cost Efficient Provisioning of Wireless Access”, licentiate Thesis in Telecommunications, KTH Stockholm, Sweden 2005.

[4] HiQ data AB, “Potential Value of Additional Spectrum for an UMTS Operator”, Stockholm, Sweden, 2004.

[5] IST-TONIC, Deliverable #11, "Final results on seamless mobile IP service provision economics”, Oct. 2002.

[6] http://nordicwirelesswatch.com/wireless/story.html?story_id=2296

[7] J. Björkdahl, E. Bohlin, "Competition Policy and Scenarios for European 3G Markets", Chalmers University of Technology, Göteborg, Sweden.

[8] http://www.wirelessbroadbandsystem.fi/bbstats.htm

[9] UMTS forum white paper, “3G/UMTS Evolution: towards a new generation of broadband mobile services”, Dec. 2006.

[10] 3GPP TS 25.346, “Introduction of the Multimedia Broadcast Multicast Service (MBMS) in the Radio Access Network (RAN) - Stage 2 (Release 6)”

[11] P. Karhu, “Emerging Mobile Service Innovation Markets: The Case of the Finnish Mobile TV Service Market”,Dissertation of the University of St. Gallen, Jan. 2007

[12] Bass, Frank (1969). "A new product growth model for consumer durables", Management Science 15, p215-227.

[13] O. Sallent et al., "Intermediate report on AROMA algorithms and simulation results", IST-AROMA Project, Deliverable D13, Apr. 2007

[14] J. Wang, "Will WiMAX+WLAN Constitute a Substitute to 3G? – A Techno-Economic Case Study", Master’s Degree Project Stockholm, Sweden March 2004

ACRONYMS

3GPP	3rd Generation Partnership Project
CAPEX	CAPital Expenditures
EDGE	Enhanced Data rates for GSM Evolution
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSUPA	High-Speed Uplink Packet Access
MBMS	Multimedia Broadcast and Multicast Service
OPEX	Operation Expenditures
QoS	Quality of service
UMTS	Universal Mobile Radio Access Network
WLAN	Wireless Local Area Network