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Topological planning and design of UMTS mobile networks: a survey

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Summary

In this paper, we present a literature review on the topological planning problem of third generation (3G) cellular networks based on the universal mobile telecommunications system (UMTS) standard. After describing the UMTS architecture, we introduce each subproblem and present major works that have been done. The cell, the access and the core network planning problems have all been considered as well as a more global approach (when more than one subproblems are considered simultaneously). Both planning and expansion algorithms are also included in this review. The goal of this paper is to present and classify the different research works that have been done so that it can be used as a starting point for future research on topological design of UMTS networks. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: third generation (3G) mobile networks; universal mobile telecommunications system (UMTS); network planning; expansion; survey; literature review

1. Introduction

The cellular industry is a very competitive market. In order to offer good rates to their subscribers, service providers need to design and update their networks so that they can provide the best services to the lowest possible cost. Designing cost effective networks is a difficult task especially in the case of large scale infrastructures with several users such as cellular networks. Since the Global System for Mobile Communications (GSM) is, by far, the most popular 2G technology, universal mobile telecommunications systems (UMTS) are expected to get the biggest share of the market as they are backward compatible with GSM networks.

The planning and design of UMTS networks have been the topic of quite a bit of research activity recently. As a result, several planning tools (methods, algorithms, and software) have been developed in order to assist the network planner with the decision-making process while optimizing operational and infrastructure costs. According to Britvic [1], network planning is a complex but necessary step when building or updating an UMTS network.

In this paper, we present a survey of the different tools proposed thus far for the topological design and planning of UMTS networks. The aim is to provide a better understanding of the current state of the art in this emerging field.

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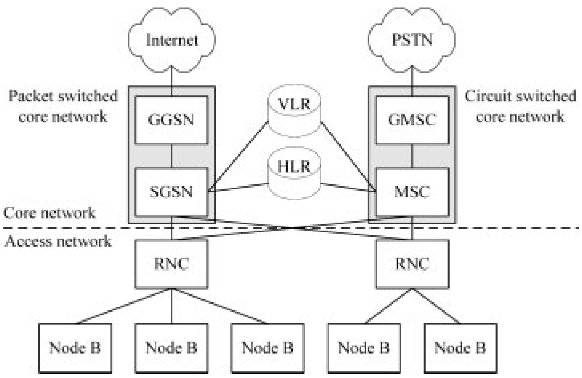

Fig. 1. UMTS network architecture.

1.1. UMTS Infrastructure

A typical UMTS [2–4] architecture is shown in Figure 1. As it can be seen, UMTS networks are divided into two different parts: the access network and the core network [5]. The former, also called UMTS terrestrial radio access network (UTRAN) [4], is composed of several radio network subsystems (RNS). Each RNS contains one radio network controller (RNC) and one or more base stations (BSs) (those who are linked to the RNC). For example, the UTRAN of Figure 1 is composed of two RNSs. The BS (also called node B) is used to transmit/receive radio frequencies to/from mobile users while the RNC deals with resources and mobility management. The main objective of the UTRAN is to make the link between mobile users and the core network.

The core network is divided into two different service domains: the circuit switched core network and the packet switched core network. The former comes from the GSM architecture while the latter inherits from the general packet radio services (GPRS). As shown in Figure 1, the circuit switched network is composed of mobile switching center (MSC) and gateway MSC (GMSC) and ultimately provide access to the public switched telephone network (PSTN). On the other hand, the packet switched network is composed of serving GPRS support node (SGSN) and gateway GPRS support node (GGSN). The MSC takes care of telephone call setup and routing while the SGSN covers similar functions for data packets. GMSC and GGSN are higher level switching devices used to route the traffic to other external networks. Moreover, the core network also contains various databases such as the home location register (HLR) and the visitor location register (VLR) in which relevant information on each client is stored (such as the current location of the subscribers).

2. Decomposition Approach

The planning problem of 3G networks is very complex to solve. In order to reduce its complexity, a decomposition (modular) approach is generally used. As a result, the planning problem of UMTS networks has been divided into three different subproblems [6]:

- The cell planning subproblem.
- The access network planning subproblem.
- The core network planning subproblem.

As shown in Figure 2, the output of the first subproblem is given as input to the second subproblem and so on until we obtain the final solution for the whole problem. Each subproblem also has their own inputs as we will see in the next sections. Finally, each of these subproblems has been demonstrated to be NP-hard [7–10].

In the following subsections, we describe each subproblem and present major works aimed at solving them.

2.1. Cell/Base Station Planning

As shown in Figure 3, the general idea behind the cell planning problem is to cover all mobile users in a given area with the minimum number of BSs. More precisely, the cell planning problem usually deals with one (or more) of the following items:

- The optimal number of BSs.
- The best location to install the BSs.
- The type (or model) of BSs.

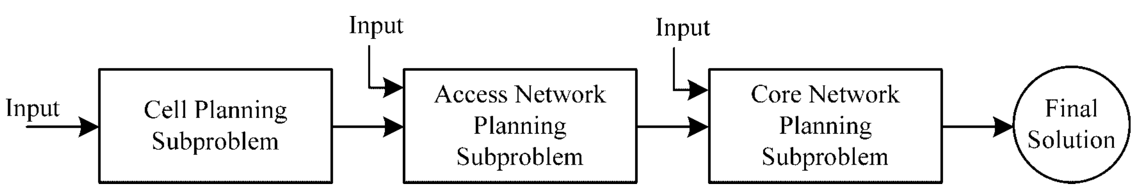

Fig. 2. UMTS planning subproblems.

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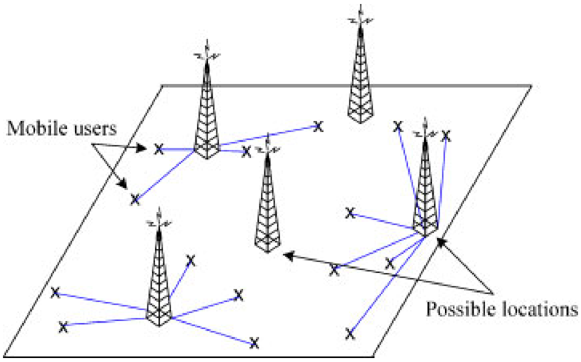

Fig. 3. Cell planning problem.

- The configuration (height, orientation, tilt, power, etc.) of BSs.
- The assignment of mobile users to the BSs.

The objective of the cell planning problem can vary depending on the network planner objective. Usually, the network planner is interested in minimizing the cost of the network, maximizing the signal quality and maximizing the coverage in a given area. Most of the time, these objectives are contradictory. For example, if the network planner wants to maximize the coverage, he will need to deploy more BSs thus, increasing the cost of the network. In their papers, Maple *et al*. [11] and Jamaa *et al*. [12] talk about a multi-objective function in which different objectives are given a certain weight (between 0 and 1). This weighted multi-objective function gives more flexibility to the network planner because he can assign higher (lower) weight to put more (less) emphasis on a given objective. Similarly, Thiel *et al*. [13] propose a simulated annealing (more details about simulated annealing can be found in Reference [14]) algorithm to help in the site selection process. The objective function is a linear combination of different criteria such as the cost, interference, coverage, balanced traffic, and so on. Their planning tool can be either tuned for speed (smaller execution time) or quality (better solution). However, no distinction is made between the uplink and downlink directions.

As stated by Thiel *et al*. [13], different inputs are required in order to solve the cell planning problem. Usually, we need to know the following:

- The potential locations where BSs can be installed. In theory, BSs can be installed anywhere. However, several constraints such as the geography, do not make it possible in practice. That is why a discrete set of possible locations is generally used.
- The different types (or models) of BSs that are available. This includes (but not limited to) the cost and the capacity (power, sensitivity, switch fabric capacity, etc.).
- The users distribution and their required amount of traffic (for voice and/or data).
- The coverage/propagation prediction.

In second generation (2G) networks (such as GSM), two different steps are required to plan the BSs [5,13,15–17]. The first step is to find a subset of BSs that maximizes the coverage. This simply ensure that the signal, using different propagation techniques, can reach the maximum number of mobile users. Once we are satisfied with the coverage, the next step is to allocate different channels (frequencies) to the BSs in order to minimize interference in the network while being able to reuse the frequencies in other parts of the network. A first paper by Neubauer and Toeltsch [18] and a second by Ramzi [19] outline the main differences at the radio level between GSM and UMTS networks. They also explain the different steps in order to plan the radio portion (also called radio access network—RAN) of UMTS networks. Finally, they stipulate that when using good planning tools, return on investment (ROI) can be maximized.

2.1.1. Mobile users/traffic modeling

An important issue when planning a cellular network is how to model the traffic (or mobile users). A first method could be to represent each mobile user with a point on the plane. If the traffic distribution is unknown, then a regular point grid could be used. However, when planning cellular networks, the number of users is very large. As a result, we need some clustering or agglomeration in order to reduce the computational complexity [16]. These agglomerations are often called traffic nodes [16] or test points [7]. Therefore, one test point can be used to represent several mobile users in a given area.

2.1.2. Air interface, propagation models and power control

The cell planning problem is complex because it involves radio frequencies. A paper by Gould [20] describes some of the challenges that will face radio network design engineers in planning their networks in urban areas. When dealing with radio frequencies, different aspects such as signal propagation, attenuation and interference must be considered. Signal propagation can be obtained using actual measurements. However, the latter is very complex and requires a lot

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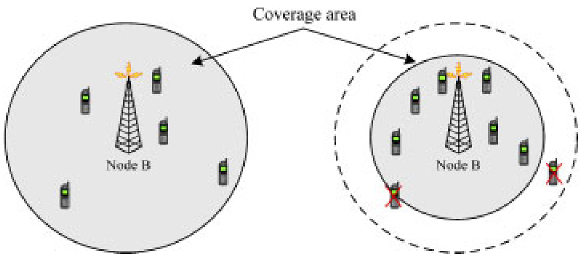

Fig. 4. Cell breathing effect.

of data (measurements). That is why different models have been developed in the literature. From experimental results and statistical data, Okumura [21] developed several practical charts in order to predict signal propagation. Later, Hata [22] derived from Okumura curves an empirical formulation for the propagation loss. This model, called the Hata model, is widely used in telecommunications networks. Other models, such as COST 231 [23], extends the model proposed by Hata to the upper frequency band (1500 Mhz $\leq f \leq$ 2000 Mhz). More information on propagation models (such as ray tracing) can be found in Reference [24].

Since UMTS networks are using the wideband code division multiple access (WCDMA) for the air interface, no channel allocation is necessary [16]. With this scheme, the capacity of each cell is based on the interference level which depends on the emitted power [7]. Instead of sharing the frequency spectrum as in 2G networks, users share the power. In fact, the amount of power allocated to a given user depends on its location. That is why a power control mechanism is required. On one side, a cell can cover a large number of users if they are relatively close to the BS. On the other side, the cell will only be able to cover a few users if they are located far away from the BS. This phenomenon makes reference to the cell breathing effect. As shown in Figure 4, the cell breathing effect can be defined as the constant change in the coverage area with respect to the amount of traffic. When a cell becomes overloaded, the interference will increase and therefore its size will decrease. Users that are excluded from the cell will usually be redirected toward neighborhood cells. It is important to keep the transmission power of the BSs and mobile users at minimum levels while ensuring adequate quality at the receiver [25]. More details about WCDMA and power control can be obtained in References [2,5,26].

Power control has a huge impact on the coverage and the capacity of the network. That is why it is important to consider it while planning the radio part of the network. In a recent paper, Yang *et al*. [25] propose a mathematical model for UMTS radio network planning which considers the power control and soft handover. They also evaluate and compare the performance of three heuristic algorithms (genetic algorithm, simulated annealing, and evolutionary simulated annealing).

2.1.3. Radio planning algorithms

Different models and methods have been developed to find the optimal topology of the cells. Given a traffic demand and potential locations to install BSs, Chamaret *et al*. [27] propose a basic mathematical model (using graph theory) for the radio network subproblem. In fact, their model only considers the coverage aspect and does not take into consideration the capacity, the traffic demands, and the BS characteristics. However, they test their model with real geographical data. Similarly, Farkas *et al*. [28] propose a genetic algorithm (see Reference [29] for more details about genetic algorithm) in order to provide an adequate service level. On the other hand, Galota *et al*. [30] propose a polynomial time approximation scheme for BS positioning in UMTS networks. Given the traffic demand and the possible BS locations, the goal of their algorithm is to keep the construction cost below a certain limit, cover the maximum number of users, and keep interference low. These three models are interesting but do not consider all aspects of WCDMA networks. No mention of power control mechanisms and signal to interference ratio can be found.

In a first series of papers, Amaldi *et al*. [7,8,31,32] propose two discrete mathematical programming models in order to find the optimal location of BSs in the uplink direction (from the mobile users to BSs). The uplink direction is important when the traffic is balanced between the uplink and downlink direction such as voice calls. When planning the uplink direction, the important constraints are the emission power of mobile users and the sensitivity of the BSs. Two different power control mechanisms are put forward. The first one is a power-based power control mechanism. With this scheme, the power is adjusted such that each channel receives the same target value. The second model, based on the signal to interference ratio (SIR), adjusts the power such that the SIR value is set to the target value. Since the problem is NP-hard, they also describe several approximative methods. They first propose three greedy algorithms (add, remove, and a combination of the two) followed by a tabu search (more details about the tabu search principle can be found in Reference [33]) heuristic (single run

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and multi start) in order to find good solutions within a reasonable amount of computation time.

In a second series of papers, Amaldi *et al*. [34,35] deal with the downlink direction (from node B to mobile users). The downlink direction is very important when the traffic is asymmetric (such as web browsing, database request, and so on). When planning the downlink direction, the major constraints are the maximum power of the BSs and the sensitivity of the user devices. Once again, randomized greedy procedure and tabu search algorithm are proposed. Experimental results for realistic instances are reported.

In subsequent papers, Amaldi *et al*. [36] and with the help of Signori [37] enhanced their previous models (in the uplink direction) such that it can not only find the optimal location of BSs but also the optimal configuration. They consider various aspects such as antenna height, tilt (vertical orientation), and sector orientation. A tabu search heuristic is also proposed. Another paper by Wu and Pierre [38] proposes a similar model but for the downlink direction. They introduce a heuristic as well as stochastic optimization techniques.

Finally, Amaldi *et al*. [39,40] propose one of the most complete model in which both the uplink and the downlink directions are considered simultaneously. They present a mathematical programming model (which is basically the combination of previous models) to optimize the location and configuration of BSs. The goal of their algorithm is to maximize coverage and to minimize cost. They also propose a simpler power control mechanism in order to reduce the computational time required. Voice and data traffic are considered.

Jamaa *et al*. [41] propose manual and automatic strategies in order to optimize the network performance in terms of capacity and quality of service given a satisfactory coverage level. Manual design only involves the modification of a small number of parameters. Another paper by Jamaa *et al*. [42] deals with the capacity and coverage optimization. Since capacity and coverage are somehow related, they use a multi-objective formulation. Finally, Jamaa *et al*. [43] also propose a steered optimization strategy in order to solve local quality problems as well as answering the question of how local the optimization problem should be defined. They came to the conclusion that considering the problem too locally reduce the efficiency of planning tools and taking a too large set increase the number of required BSs thus, increasing the cost of the network. All these works are summarized in an overview proposed by Picard *et al*. [44].

A recent work by Sohn and Jo [45] also tackles the location problem and the assignment of mobile users to BSs. They propose a constraint satisfaction model and apply different techniques such as variable ordering and value ordering to get good approximative solutions. Instead of minimizing the cost of the network, they try to minimize the total transmitted power.

Finally, some papers present automatic cell planning tools. Allen *et al*. [46] introduce their tool called CDS-SmartPlan. They also present a case study for UMTS network design in London.

Once we know the location and the configuration of the BSs, the next step is to deal with the access network planning problem.

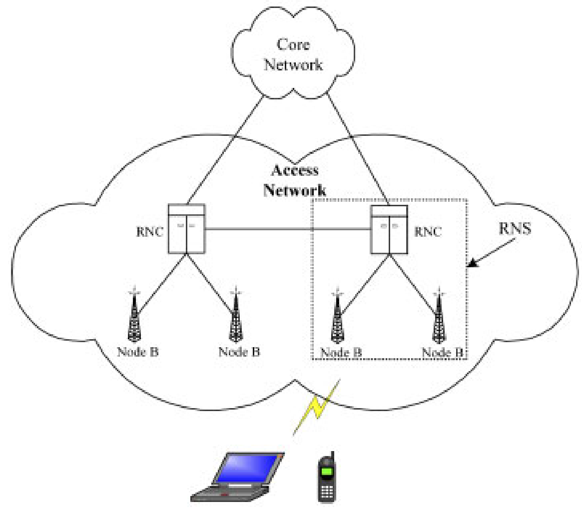

Fig. 5. Access network architecture.

2.2. Access Network Planning

The access network planning problem, as illustrated in Figure 5, consists in finding the number, the location, and the type of RNCs as well as the interconnection between the BSs and the RNCs. As in the cell planning problem, different inputs are required in order to plan the access network. These inputs usually are:

- The physical location of the BSs (can either be given or obtained by solving the previous subproblem).
- The traffic demand going through each BS (can either be given or obtained from the previous subproblem).
- The set of potential locations to install the RNCs.
- The different types (models) of RNCs.
- The different types of links available to connect the BSs to the RNCs.
- The handover frequency between adjacent cells.

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Most of the time, the objective function consists to minimize the cost. Other objectives such as reliability can also be considered (see Subsection 2.2.1).

Depending on the assumptions, BSs can either be linked directly to the RNC or cascaded. In both cases, the physical topology of the network is a set of trees. In a first paper, Harmatos *et al*. [47] proposed an algorithmic solution that optimizes simultaneously the number and the location of the RNCs as well as the transmission network. A degree constraint on the maximum number of BSs that can be supported by one RNC is also considered. Their solution is based on the combination of the simulated annealing and a greedy algorithm. They also state (without demonstration) that their algorithm can be used to update an existing network. An update (also called expansion) problem is much more complex than a planning problem. In fact, the expansion problem is a generalization of the planning problem. Therefore, an expansion model can be used to plan a new network and update an existing one. The expansion problem can be defined as follow: given equipments that are already installed (BBs, RNCs, MSCs, SGSNs, etc.), how can we reorganize the network in order to meet the new demand?

In a second paper, Harmatos *et al*. [48] found that the bottleneck of their previous algorithm [47] was the tree construction. Therefore, they proposed a new algorithm in order to build an access network for only one RNC. Since this is closely related to the spanning tree problem (see Camerini [49] for more details about the spanning tree), they say that their algorithm can work for any multi-constrained capacitated tree optimization problems with nonlinear cost function. In a further paper, Jüttner *et al*. [10] improved the first two methods in order to obtain better results. The first method is a global algorithm that combines a metaheuristic technique with the solution of a specific b-matching problem. The second method uses Lagrangian lower bound with branch and bound and is able to plan (or to make corrections to) a single tree.

In another paper, Lauther *et al*. [6] handle the access network planning subproblem as a clustering problem. Given the location of BSs, they present two clustering procedures based on proximity graph. The first method is based on tree generation and cutting. The basic idea is to build a tree (e.g., using Prim or Kruskal algorithms) and then separate the tree into two subtrees, each one representing a cluster. The second method is based on the generation of subtrees starting from the leaves. Initially, each node B form its own cluster. At each iteration, two clusters are merged if the cost of the access network is reduced.

A series of papers by Wu and Pierre [50–52] propose a constraint-based optimization model used to find the optimal location of RNCs and, at the same time, optimally assigning the BSs to the selected RNCs. The number of Node Bs that can be supported by a single RNC is finite and determined by the number of available interfaces (ports) on the RNC. Similarly, the amount of traffic that can be supported by a single RNC is also finite. They also consider the notion of simple and complex handovers while assigning BSs to RNCs. For example, if the number (or the frequency) of handovers between two adjacent cells is high, then it would be recommended to link these two cells to the same RNC in order to have simple handover (complex handovers consume much more network resources). This concept is very similar to the cells to switches assignment in 2G networks. Therefore, similar models such as in References [53–55] could be used.

A recent paper by Bu *et al*. [56] focuses on the way information is transferred between the BSs and the controllers (RNCs). Usually point to point links (such as T1 and/or E1) are used. They advance that this is not a good match for next generation networks because these networks carry bursty and asymmetric data traffic. Therefore, they propose to use a 802.16 (WiMAX)-based wireless RAN to carry the traffic from node Bs to RNCs. Given the BSs and RNCs position, they design the access network in order to minimize the number of 802.16 links used. Similarly, since data traffic can be bursty, Charnsripinyo [57] proposes a model and a heuristic in order to plan the access network with an acceptable level of quality of service.

2.2.1. Planning reliable access networks

Network reliability (also known as network survivability) is an active research topic these days. In fact, recent terrorist attacks combined with an increasing number of natural disasters put an emphasis on the need to 'secure' communications networks. As stated by Tipper *et al*. [58], survivability is used to describe the available performance of a network after a failure. Typical failure examples include single node (BS, RNC, MSC, SGSN) and link failures. Due to their unique characteristics (user mobility, power control, etc.), cellular networks can be severely affected by failures. For example, a BS failure will put a lot of pressure on the neighborhood cells as mobile users will try to get coverage from them. In a first paper, Tipper *et al*. [58] presented a survivability analysis for cellular networks with a focus on voice networks. They also identified metrics for quantifying network survivability.

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Obviously, reliability comes with a cost. The idea is to find the best tradeoff between cost and reliability [59]. In order to find this tradeoff, different methods need to be developed. Szlovencsák *et al*. [59] proposed two algorithms in order to minimize the cost of the access network while respecting a predetermined reliability level. Starting from a minimum cost tree as proposed in References [47,48], the first method consists to redesign the tree while considering reliability. New links will be added and some other will be removed but the tree structure will always remain. This method will achieve higher reliability but is still vulnerable to link and node failure. The second method consists to add different links to the tree structure in order to protect the most vulnerable parts of the network.

More recently, Charnsripinyo and Tipper [60] proposed an optimization-based model for the design of survivable 3G wireless access using a mesh topology. The objective is to minimize the cost of the network while respecting the quality of service and survivability constraints. They adopted a similar two-phase methodology. In the first step, they build the minimum cost topology while taking into consideration the quality of service requirements. In the second step, they update the network topology in order to meet the survivability requirements. In order to solve 'real-size' problems, they proposed a heuristic based on iterative minimum cost routing.

Once we know the number, the location and the traffic going through each RNC, the next step consists to plan the core network.

2.3. Core Network Planning

The core network (as shown in Figure 6) is the center of the network. It gives access to external networks such as the PSTN and the PDN. Given the location and the traffic going through each RNC, the core network planning problem consists in finding the number and the location of the network elements (MSC/SGSN) as well as the interconnection with the RNCs.

Very few research have been made on the core network planning subproblem. This can be explained by the fact that this subproblem is similar to the wired network planning problems. Therefore, no specific methods are required. However, some researchers have focused on this subproblem.

A first paper by Ricciato *et al*. [61] focuses on the assignment of RNCs to SGSNs based on measured data. Their objective is twofold: balance the number of RNC per SGSN and minimize the inter-SGSN routing. While they focus on GPRS networks, they state that

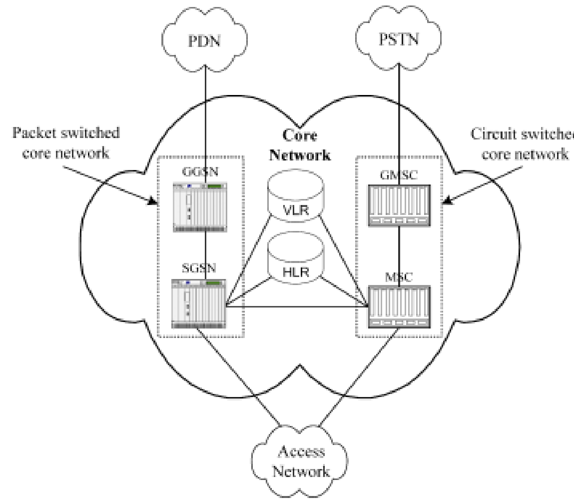

Fig. 6. Core network architecture.

the proposed approach can also be applied to UMTS networks.

Another paper by Harmatos [9] deals with the interconnection of RNCs, the placement of media gateways (MGs) and planning the core network. Because of the complexity, Harmatos divided the problem into two parts. First, he finds the location of MGs and a reasonable topology using a linear cost function. In the second part, he uses the real cost function (step function) in order to reduce the cost of the network. One important feature of this paper is that it makes abstraction of the network equipments. Therefore, different technologies (IP, ATM, etc.) can be used without changing the algorithm.

Finally, in a more general paper, Shalak *et al*. [62] discuss the required changes at the core network level so that service providers will be able to progressively migrate from GSM to UMTS. They also outline the various planning steps as well as describing available equipments on the market.

2.4. Decomposition Approach: Concluding Remarks

As stated before, the goal of using a decomposition approach is to reduce the complexity of the problem. In fact, we end up with three different subproblems where each one is easier to solve than the whole problem. Another advantage of the decomposition approach is that a better planning can be done. Since each subproblem is easier to solve, more details can be considered.

A decomposition approach also has drawbacks. The major disadvantage of this approach is that each

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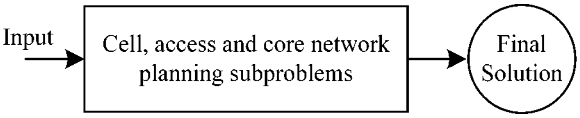

Fig. 7. Global approach.

subproblem is consider independently from each other thus, resulting in a local optimization. Most of the time, combining the solutions of each subproblem do not provide an optimal solution to the global problem. Moreover, no integration techniques (or strategies) have been developed to incorporate all partial solutions in order to obtain a global solution. Integration techniques are very difficult to develop because we need to have a global view of the network.

A different way of solving the planning problem of UMTS networks consists in using a global (also called integrated) approach.

3. Global Approach

A global (integrated) approach consists in considering more than one subproblem simultaneously. Since all interactions between the subproblems are taken into consideration, a global approach has the advantage of providing solutions that are closer to the global optimum. When the three subproblems are considered simultaneously, as shown in Figure 7, optimal solution can be obtained. However, the problem becomes more complex.

As we mentioned earlier in Section 2, each subproblem is NP-hard. Therefore, we can assume, without any doubt, that the global planning problem is also NP-hard.

Instead of dividing the UMTS network planning problem into different subproblems, some authors tackle two (or three) subproblems simultaneously.

3.1. Global Planning Algorithms

Since the UTRAN accounts for 70–80 per cent of the total expenditure of the network [63], Zhang *et al.* [63] propose an integrated approach for solving the first two subproblems (cell and access). Their paper deals with the number and location of the network elements (BSs and RNCs) as well as the interconnection between them.

Given the BS locations, Chamberland and Pierre [64] propose an optimization model to plan simultaneously the access and the core network of 2G networks. While this model is targeted to GSM networks, it can also be applied (with minor modifications) to UMTS networks. Their model selects the location, the type of equipments, and the type of links as well as the design of the network topology. Since this kind of problem is NP-hard, they propose a tabu search algorithm and compare their results with a generated lower bound.

In another paper, Chamberland [64] developed an expansion model specifically aimed for UMTS networks. Considering an update in the BS subsystem (new BSs are added), the model determines the optimal access and core networks while considering network performance (e.g., call and handover blocking). He propose a mathematical formulation of the problem and a heuristic based on the tabu search principle.

More recently, St-Hilaire *et al.* [66,67] proposed an integrated approach in which the three subproblems are considered simultaneously (see Figure 7). In fact, they developed a mathematical programming model to plan UMTS networks in the uplink direction. They present a detailed example in order to compare their global approach with the sequential approach (when the three subproblems are solved successively). Due to the complexity of the problem, they also proposed heuristics based on local search and tabu search [68].

Following the same veins, St-Hilaire *et al.* [69] proposed a global model for the expansion problem of UMTS networks. This model, which is an extension of References [66,67] can be used not only to plan a network but also to update an existing infrastructure. This model fits real life situations in which mobile users have the choice to subscribe or to leave a service providers. Numerical results based on a branch and bound implementation [70] are presented.

4. Conclusion

The main goal of this paper was to review major works that have been accomplished in the area of topological planning of UMTS networks.

As we saw, the planning of UMTS networks is quite complex. Both the decomposition approach and the global approach are NP-hard to solve. However, with all the researchers dedicated to this problem, several algorithms and methods (exact and approximative) have been developed to assist the network planner in his task. These tools can minimize the capital investment required to build a new network or to update an existing one.

On one hand, a decomposition approach breaks the problem into three smaller subproblems: the cell, the access, and the core network planning problems. Optimal and/or approximative solutions can be

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found for each of these subproblems. Since these subproblems are smaller, they can be solved much faster. However, if the network planner is looking for an optimal solution for the whole network, the combination of these optimal solutions might not provide an optimal network. On the other hand, a global approach considers more than one subproblems simultaneously. Using this approach ends up more costly in terms of computation time because the problem (model) is much more complex to solve. However, optimal solutions can be obtained if we want to plan a whole network. All being considered, a tradeoff between these two approaches could provide good quality solutions with reasonable execution time. An example of such a tradeoff could be an iterative sequential algorithm in which each subproblem is solved one after the other. At each iteration, different parameters could be changed thus producing different possible solutions.

When planning UMTS networks, several issues still need to be resolved. In fact, all the previous models are making assumptions that may not represent real life scenarios. For example, the amount (and the distribution) of traffic is really difficult to predict especially as we are integrating more data services. Another important aspect is that we need to consider both directions (uplink and downlink) simultaneously in order to carefully plan a network. Finally, a last limitation deals with the structural organization of companies. In general, companies are composed of several autonomous departments. Therefore, we may end up with a department that deals with the radio part and another department that handles the network part. Therefore, a great cooperation is required between the departments in order to get optimal planning.

As we are moving toward 4G networks, all these planning tools should adapt themselves to reflect the changing reality of cellular networks. The keyword of 4G networks is 'integration'. In fact, 4G networks will be an integration of different access networks (Wi-Fi, Wi-Max, UMTS, etc.) around a single IP (Internet Protocol) core network. This new generation will bring a lot of challenges such as handovers between different access networks (also known as vertical handovers), end-to-end QoS, pricing/billing, and so on. As a result, new planning tools will be necessary in order to consider these issues.

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