A Systematic Approach For UMTS RAN Design

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Abstract

If there were not the variable spreading factor, the choice of link parameters and the packet switched data communication, the 3G-radio network (RN) design would not at all differentiate itself from the well-known 2G CDMA design. The paper emphasizes 3G design specific features as required by UMTS RAN. It delves into the 3G radio network traffic engineering, the service mapping and significance for RN capacity, the selection of key system parameters like the synchronization (SCH) and common pilot (CPICH) powers, as well as the operation of 3G design tools.

I. Introduction

UMTS is the Wideband Direct-Sequence Code Division Multiple Access (WCDMA) technology supported by ETSI/SMG for the next mobile radio generation (3G). UTRAN is the acronym for UMTS terrestrial radio access network. The inherently wide (5 MHz) RF bandwidth of WCDMA accommodates high user data rates and has also certain performance benefits, such as increased multipath diversity. With a chip rate of 3.84 Mcps, UTRAN is capable to discriminate multipath as close as 260 ns, the 78 m difference in the path lengths being beneficial for small cells deployments.

Bandwidth on demand (BoD) through variable data rate is made possible by the Orthogonal Variable Spreading Factor (OVSF) technique. For example, the data rate for UTRAN downlink physical channel range from 30 Kbps to 1920kbps. Data rate and format may change every frame (10 ms).

The BoD concept opens the door for providing countless services with assorted bandwidth, quality of service and traffic models. Such a diverse traffic demand distinguishes 3G from traditional 2G and makes traffic engineering a design centerpiece.

UTRAN supports asynchronous base station operation that simplifies deployment of indoor and micro base stations. The air interface allows advanced CDMA receiver concepts, such as multiuser detection (MUD) and smart adaptive antennas, to be easily deployed as system options for increase capacity and/or coverage. UMTS has a TDD version that has been devised mainly for in-door coverage.

The multiple access interference (MAI) of 3G networks shows large random changes on a smaller time scale when carrying a lot of PS data traffic as for the CS speech traffic. Special attention must be given to the network spatial reliability which guarantees that traffic demands are satisfied within the whole network, independent of the traffic mix, traffic environment, etc.

The paper is organized in four sections. The first section explores the radio network traffic engineering that is linked with the quality of service (QoS) given the mix of service classes and traffic demand. The second section shows the importance of service mapping on network capacity. Criteria for selecting key system parameters are presented in section three. The last section emphasis on the medium access power control algorithm that is fundamental for understanding the WCDMA design approach

II. Traffic engineering

3G radio network traffic engineering is concerned to find out the number of channels (spreading codes) required for conveying the traffic mix and achieving the QoS objectives.

Circuit switched (CS) traffic engineering (Figure 1) is usually based on the Erlang B model. For a given blocking probability (PB) and total traffic load (A) the number of RF channels are evaluated.

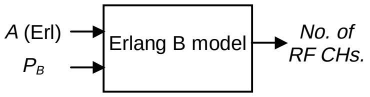

Figure 1 CS-traffic engineering

For some PS-traffic classes the M/M/n model [1] may be used for calculating the required number of common RF channels[1] for achieving given objectives of average delay (and/or maximum delay percentile). Assuming a service class described by the per user average packet size $E\{l\}$ and packet arrival rate λ_o, the minimum number of channels N required for the average delay objective $E\{T\}$ is given by (1)

$$N \geq \frac{E\{l\}}{R \cdot E\{T\} \cdot (1+\eta)} + n \cdot \rho_o \qquad (1)$$

The result factors in the RF channel rate R, the transmission efficiency η, the number of subscribers n and the link efficiency $\rho_o = {}^{\lambda_0}\!/_{\mu_0}$, where μ_0^{-1} is the average packet service time. A similar equation may be derived for M/D/n traffic models also.

Any of the above models would represent a poor description of the web-traffic profile for individual subscribers. Modeling such traffic requires new concepts such as: web sessions, pages per sessions, packets per page and reading time between pages. Due to the subscriber interaction with the web-traffic flow, as

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[1] Servers in traffic engineering terminology

described by reading times, the epoch of each page within a web-session is specified relatively to the absolute time of the web session.

As long as no closed form solutions are available for the web traffic as well as for mixtures of traffic, a wireless traffic simulator has to be used for selecting the number of channels required by the 3G air interface when the traffic demand and the QoS objectives are given. By modeling individual subscriber traffic, the simulator addresses only the radio network contribution to the end-to-end QoS.

Such simulators encompass a large range of traffic models from the simple Poisson arrivals and exponential service time (M/M/n), to On/Off sources and self-similar. Various scheduling policies and statistics are available for the page (packet) size (exponential, geometric, normal, etc) and the reading time (constant, exponential, Pareto, etc). *Web-browsing study case*

An event driven simulator (3G-WTEA) has been developed for studying the radio network traffic. The traffic demand, the subscriber traffic profile per service and the QoS objective represent the inputs. 3G-WTEA outputs the queue statistics and time evolution and the cumulative distribution function (CDF) for page/packet delays. The CDF is used for computing the average delay and the percentile for a given maximum delay. Simulation starts with an initial number of channels given by the non-congestion condition $\lambda/\mu < 1$. The number of channels is incremented until the maximum delay percentile traffic is reached.

The input for the study case is given in Table 1. For the initial number of channels (N=7), the QoS objective is not reached; 95% of the pages transmitted over the air interface are delayed by more than 2 seconds (Figure 2).

Table 1 Input data for the web-traffic study case

- BH average traffic demand: 192 MB
- Web Session (WS) Inter-arrival Time Statistics: Exponential (0.6sec)
- Number of Web Pages (WP) Statistics per WS: Geometric (5)
- WP Size: Normal (6400,800)
- Reading time (RT): Exponential (2sec)
- QoS: α=95%, Percentile delay (2 sec)

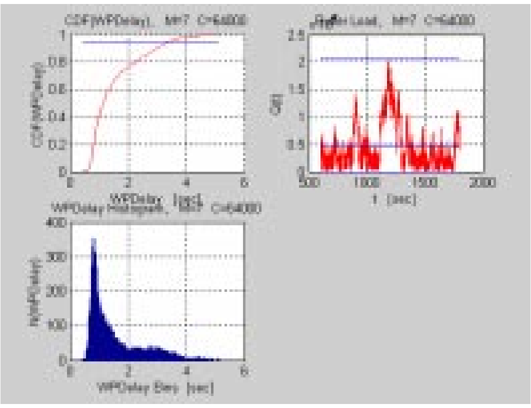

Figure 2 Web-traffic QoS for 7 channels

Increasing the number of channels to N=8 (Figure 3), the buffer load is reduced and the delay objective is achieved. The actual delay for the 95 percentile may be read from Figure 3 chart CDF(WPDelay).

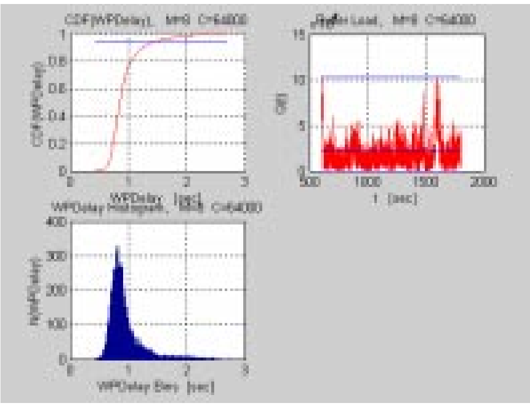

Figure 3 Web-traffic QoS for 8 channels

III. Service mapping

Any given 3G service may be transported over the air interface in many different ways. Physical channels (service bearers) can be defined by a set of parameters usually named the *transmit format*. Each bearer has a specific *operating point* (EbNo at a given BER or BLER) as a function of the transmit format, the propagation environment (power delay profile and propagation model) and user mobility.

B. Service operating point selection

For a given bearer and subscriber mobility, the operating point changes with the propagation environment. Such changes are more severe for low mobility and high data rate services. Figure 4 shows link level simulation results for LDD144 service (144 Kbps, low delay data) and ITU [2] propagation environments.

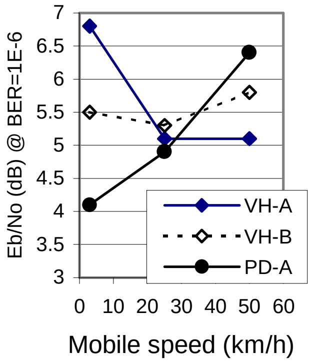

Figure 4 DL operating point for LDD 144 service

According to the figure, the selected bearer (Table 2) is optimal only for the propagation environment PD-A (outdoor to indoor type A). For the propagation environment VH-A (Vehicular type A), the operating point of the same bearer would be 6.8 dB. This example is conclusive enough for the importance of controlling the propagation environment and using the proper transmit format (bearer) for it.

From cell capacity perspective, assuming 10% DL orthogonality and 0.66 frequency reuse, the two operating points translate into a pole capacity of M=15 and M=8 for 4.2 and 6.8 dB respectively.

Table 2 LDD144 DL-bearer configuration

Bearer configuration	Downlink
Service	144 kb/s
Frame size	10 ms
Info bits / frame	1440
Bit per radio block *	120
Tail/CRC bits per radio block	8/0
Turbo code	Rate 1/3, 8 states
Decoding algorithm	Max-Log MAP
Number of iterations	8
Unequal repetition	Not used
DTX	320 bits
Outer interleaving (10 ms)	72×64 bits
DPCCH (pilot/TPC/TFCI)	16/8/8
DPCCH-DPDCH power	0 dB
Spreading factor (DPDCH)	8
Spreading factor (DPCCH)	8

* A radio block is a group of bit to which a CRC word is appended.

Service mapping looks for the best bearer (lowest operation point) to be used in each area of the markets. Thus, in contrast with 2G CDMA design, in a 3G network the same type of service may end up by being mapped to different bearers in different areas of the market. Based on measurements and assumptions, the coverage area objective is divided into disjoint geographical areas, each one being characterized by a representative propagation environment. Then, based on user mobility assumptions and type of service to be provided, the bearer with the lowest operating point is selected for each area.

The need for characterizing the propagation environment is 3G specific. Link level simulations (LLS) emphasize the operating point sensitivity to this radio parameter. ETSI and ITU-R have defined four propagation models (outdoor-to-indoor A and B, and vehicular A and B) but these models are too generic to be used in a real design. Wide band channel sounding must be considered for getting actual propagation environment knowledge.

C. Results of link level simulations

The lowest operating point for voice services happens for pedestrian mobility, when the fast power control and carrier recovery algorithms are very efficient. Still, the operating point is sensitive to the propagation environment. For a large mobility range (25÷250 km/h) the operating point does not change and it is almost independent of the propagation model [3]. The interleaver function compensates for the reduction of effectiveness of the power control and carrier recovery algorithms. At very high mobility (350÷500 km/h), neither of these techniques is able to counteract the channel impairments and the performance degrades rapidly.

For low delay data (LDD) and high data rate services, the air interface becomes more sensitive to the propagation environments. The lower spreading factor causes problems to the Rake receiver in discriminating multipath components and recovering signal energy. The BER floor that usually shows in such cases may be alleviated by properly administrating the branches of the Rake receiver.

For unconstrained delay data services, automatic repeat request (ARQ), turbo coding and long interleave intervals are techniques available to lower the bearer operating point.

IV. Key system parameters

As for any CDMA design, key system parameters required by UMTS are the synchronization (SCH) and common pilot (CPICH) channel powers and soft handoff thresholds. The present section will focus on the common channel powers while the SHO thresholds will be addressed in section V.

Cell search in UMTS/W-CDMA is one of the major differentiators from 2G CDMA. This departure from 2G CDMA systems results from the original goal of devising a CDMA network that may operate in synchronous and non-synchronous mode. Cell search is performed in two scenarios: *initial* and *target* cell search. The initial cell search happens when a terminal is turned on. Target cell search takes place for network-connected terminals that may be in idle or active mode.

In W-CDMA, a cell is identified by its downlink scrambling code. Cell search is performed by every mobile station in the network for acquiring code and time synchronization with the scrambling code of the best server. Three system channels are used in this process: the Primary Synchronization Channel (P-SCH), the Secondary (S-SCH) Synchronization Channel[2], and the Common Pilot Channel (CPiCH).

The powers used for the aforementioned common channels are key parameters in network design whose selection reduces to a cell capacity - cell acquisition time trade-off. The loading factors for different channels are defined in equations (2)÷(4), where P_X denotes transmitted power for channel X while I_{oc} and I_{hc} stands for other-cell interference and home cell interference respectively.

$$\chi_{P-SCH} = P_{P-SCH} / P_{SCH} \tag{2}$$

$$\chi_{SCH} = (P_{SCH}) / (P_{SCH} + P_{CPiCH} + I_{hc}) \tag{3}$$

$$\chi_{CPICH} = P_{CPICH} / (P_{SCH} + P_{CPICH} + I_{hc}) \tag{4}$$

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[2] P-SCH and S-SCH are the components of the Synchronization Channel (SCH)

In order to quantify how close the MS is to the center of the cell, a geometry factor *G* is defined as the ratio between the power of signal coming from the desired BS and the other cell interference [4]. Typical values for *G* are in the range of –6 to 6 dB. The higher the geometry factor the closer to the node-B the terminal is

$$G = \left(P_{SCH} + P_{CPICH} + I_{hc}\right)/I_{oc} \qquad (5)$$

The cell search algorithm may use coherent or non-coherent detection. The designer must pay attention to this detail because, at least for initial search, the two options result in quite different cell search times. Usually, the initial search takes longer than the target search.

High values for the SCH and CPICH loading factors result in fast acquisition time at the expense of high interference to other physical channels in the same cell. The interference coming from the SCH is less significant because it is broadcasted only 10% of the time.

Analyzing the average acquisition time for different CPICH loading factors (Figure 5), little improvement may be seen by increasing χ_{CPICH} over 10%. The minimum usable CPICH loading factor could be 5%, below this figure the cell search time becoming unacceptable long. In the same time, low CPICH powers worsen the channel estimation output, degrading the operating point (Eb/No target increase) for the 3G bearers in that cell.

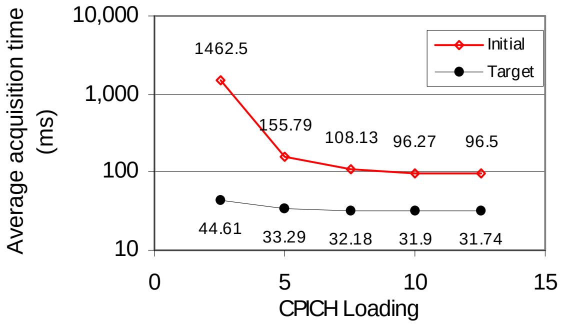

Figure 5 Average acquisition time versus χ_{CPICH} (G= – 3 dB, χ_{P-SCH}=50%, χ_{SCH}=10%)

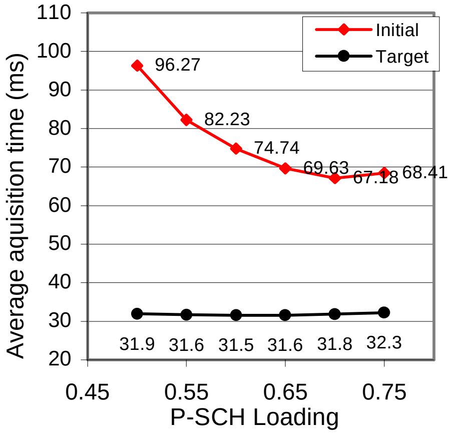

Figure 6 Average acquisition time versus χ_{P-SCH} (G= – 3 dB, χ_{SCH}=10%, χ_{CPICH}=10%)

The cell acquisition time becomes to long when the SCH loading factor is below 10%. With χ_{SCH}=10%, the average interference power coming from SCH is 1% of the cell transmitted power. The SCH power has to be divided between P-SCH and S-SCH. A good choice for the P-SCH loading factor is approximately 0.6÷0.7.

This analysis shows clearly that using the same CPICH power all over the network is a poor choice. It has to be optimized according to the load and type of traffic to be carried.

V. Radio network design

Any radio network deployment includes a pre-design (dimensioning) phase that estimates the initial network configuration. For 3G networks, link budget based dimensioning, apart from being quick, inherently includes a lot of inaccuracies emerging from many network assumptions such as: soft handover overhead and gain, fix inter-cell interference, uniform traffic distribution and uniform service mapping, etc. As an alternative, static network simulators (SNS, have been developed. The algorithms used by static network simulators are very similar to the ones used by design tools. Obviously, design tools take into account terrain databases, morphology, user defined traffic maps, etc. and perform the task on large geographical areas. Design tools couples the UMTS service coverage with the service coverage provided by incumbent 2G networks.

D. Static network simulation (SNS)

Static network simulation gives a better estimate of network capacity and operation than link budget based dimensioning. It uses link level and RN traffic simulation results for performing its tasks.

Usually, dimensioning tools are more conservative; they assume the same interference level for every cell within the network, which translates into identical cell capacity. SNS does not take any assumptions but generates interference statistics [5] that show large standard deviation namely for high data rate services. Also, it uses antenna radiation patterns instead of the antenna gains and randomly distributes subscribers and services within the network.

Static network simulation provides ways for controlling CDMA specific network parameters like the SHO overhead, the F-factor distribution, etc. SHO results as a function of the BS antenna beamwidth and SHO addition window. Table 3 illustrates the network performance for two BS antenna horizontal beamwidth: 90° and 65° respectively.

The SNS yields snapshots of the RN status at different instances in time. Based on Monte Carlo (MC) trials, each snapshot has a different spatial distribution of users and services. Multiple access power control (MAPC) algorithms are used for assigning the amount of UL/DL power required by each radio link (RL). Power being a limited resource to share in a CDMA network high traffic cells are likely to disconnect some of their users. The RN design quality and actions to be taken for optimizing it are derived by post processing the SNS snapshots' data.

Table 3 Average number of pedestrian (a) and high mobility (b) speech users

	90°	65°
UL users	(a) 31 (b) 31	(a) 36 (b)36
DL users	(a) 21 (b) 21	(a) 23 (b) 23
f	0.92	0.65
χ (loading)	0.59	0.58
DL Tx power	19.45	19.36

Basically, the network configuration and traffic scenario shape the static simulator output. The network scenario is made of BS configuration and calculation area, propagation environment areas, SHO thresholds, service mapping, etc. The traffic scenario has multiple components: the set of services and their distribution per region and subscriber type, subscriber type densities, traffic models per subscriber and service class.

BS configuration includes but is not limited to the propagation model to be used for path loss calculation, sectorization type, antenna configuration and height, maximum transmitted power, CPICH and SCH loading factors, power used by other common channel, DL bearers operating point, etc. On the MS side, configuration includes UL operating point (target EbNo) for different services, receiver sensitivity, noise factor, maximum Tx power, etc

The SNS outputs are organized as maps and databases. Maps are used for showing radio network attributes associated to each bin. The set of output plots is made of but not limited to CPICH coverage, E_c/I_t, effective service coverage, best server, SHO including active set (based on SHO thresholds), etc. Few maps, like CPICH coverage, are traffic independent but most of them include the level of interference in the network. Databases are associated to users and base stations (Node-B). They describe the status of each user generated by MC simulation and each Node-B in the working area.

Static network simulation goes through three stages: reading input data, performing MAPC for the number of snapshots specified by the user and saving and post-processing the results.

E. Multiple Access Power Control algorithm

Multiple access power control provides a way of estimating the status[3] of a CDMA radio network outside the history context. Time being suspended there is no information about the past of the network and no inferences can be made about the future. For a given distribution of users and services, the status of a real network and the one given by running MAPC algorithms might not coincide. At any moment in time, the status of a real network is the result of users' history, while snapshots do not carry such information. The statement is reinforced by the fact that for the same distribution of users/services, changing the order users are processed might change the MAPC output.

MAPC is an iterative algorithm that finds out the best server and the AS for each user (terminal) and assigns the minimum UL/DL transmit power for providing the required service at that instance. A flowchart of the algorithm is given in Figure 7.

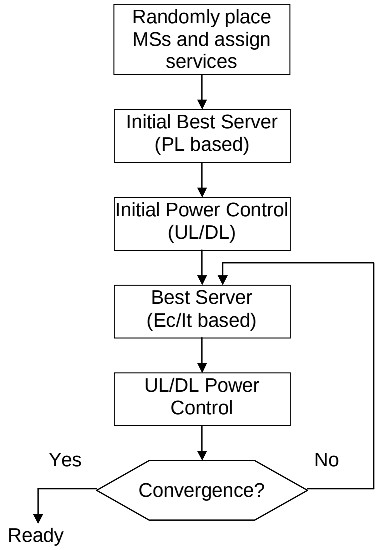

Figure 7 Power control flowchart

The first step of the algorithm randomly distributes users (MSs) within the selected work area. Each user demands a service from the service set specified in the network configuration. The number of users for each type of service is proportional with the total traffic demand for that service and the per user traffic profile.

The best server and the active set for each user are initially calculated based on path loss (PL). Such an approach only initializes the algorithm and bears no relationship with a real network where E_c/I_t is the base for deciding the best server and AS. Once, the initial cell selection process is completed, a first UL/DL power control is run for each mobile station. Uplink and downlink are considered in the same time for any MS before moving to the next one.

The UL/DL transmit power for each radio link is based on the sensitivity level at the receiver (current best server/MS) and the path loss. The result is adjusted by taking into account the activity factor for each service, the SHO gains and the average power raise due to fast transmit power control. The latter two are provided by link level simulations.

MAPC is performed until the chosen convergence criterion is reached. A counter is used for limiting the

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[3] The status of a CDMA radio network is represented by the set of user and services that are connected through the air interface.

number of iterations if the algorithm fails to converge, as might be the case for high loaded cells.

There are many UL/DL convergence indicators. For instance, the maximum taken over all relative (delta) base station sensitivities (6)

$$\Delta_I = \max_{Stations\ j} \left| I_{t,k}^{j} - I_{t,k-1}^{j} \right| \quad (6)$$

where $I_{t,k}^{j}$ is the total interference at base station j at k – eth iteration is a commonly accepted UL convergence indicator. For a user-defined threshold ε, convergence is achieved when $\Delta_I \le \varepsilon$ before the iteration counter reaches a predefined limit. Usually, uplink and downlink criteria are combined in a single convergence indicator.

F. Design options

The MAPC algorithm has several options that copy the operation of a 3G radio network. They may change the design results or even the traffic distribution.

If MAPC finds that the UL-loading factor of a cell exceeds the maximum specified by the design and the option of adding new carriers is validated, mobile stations are moved to the new carrier(s). Several inter-carrier traffic-sharing strategies are available: (a) randomly moving MSs within the entire network, (b) randomly moving MSs from overloaded cells, (c) moving only high transmit power MSs from overloaded cells. Each technique has its own drawbacks. For instance, the first strategy distributes a second carrier all over the network, even in areas where the extra spectrum would not be required.

The DL iteration is strongly dependent on the CPICH power allocation. Again, different strategies are available for allocating CPICH power, which include (a) fix CPICH power within the network, (b) adjustable power for each cell based on UL-interference level and (c) cell selectable fix CPICH power.

On the DL, once the transmitted powers for every radio link are calculated the total BS transmitted power is evaluated. If it exceeds the maximum allowed power some radio links must be disconnected. Optionally, MAPC may (a) randomly disconnect, (b) disconnect the highest power links or (c) disconnect the smallest power links. The selection of the RL dropping strategy is very important as it may change the initial traffic distribution. For instance, terminals close to the cell edge or BS will be stripped of by methods (b) and (c) respectively.

VI. Conclusions

As a result of the new air interface concepts that allow variable data rate services and real time QoS control by optimization of the radio link transmit format to the channel impairments, 3G-radio network design cannot be integrated, at least for the moment, in a single design tool. It is shown that link level and radio network traffic simulations as well as power delay profile measurements are essential components of the design. Static network simulation, a simplified design tool that does not require terrain databases but copies the functions of the design tools, may be used for locally optimizing or finding initial radio network configuration. Originally designed for UMTS, SNS may be customized for any 3G CDMA based technology.

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