Impact of mixed voice and data traffic on the UMTS-FDD performance

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Abstract—The provision of multimedia services to mobile users is one of the main goals of Third Generation (3G) systems. The traffic being transferred within 3G mobile networks will be composed by different information flows with various constraints on the required QoS (bit rate, delays, etc...). In order to reach such a goal, 3G standardization bodies have designed highly-flexible radio interfaces, characterized by a great number of physical parameters to be set by the operators. UMTS (Universal Mobile Telecommunication System) offers both circuit switched and packet switched transfer mode, and within each transfer mode, different QoS can be achieved by properly setting physical parameters such as the speed of physical channels, the power control scheme, the rate of the FEC protecting code, etc. In this paper we give an evaluation of the performance of W-CDMA UMTS radio access network (UTRA) when providing access to multimedia services. In particular, we analyze through detailed simulations a typical scenario where voice calls and web–browsing sessions share the same frequency carrier, the former using the dedicated channels (DCH), the latter being transferred on the downlink shared channel (DSCH).

I. Introduction

One of the main advantage of the 3G systems with respect to the second generation is the capability of providing radio access to multimedia services in an efficient and cost effective way. The traffic being transferred within 3G mobile networks will be composed by different information flows with various constraints on the required QoS (bit rate, delays, etc).

Universal Mobile Telecommunications System (UMTS) [1] is the third generation mobile communication system standardized by 3GPP, the Third Generation Partnership Project [2]. The UMTS terrestrial radio access network (UTRA) is devised to provide access to different services ranging from the classical speech service (8-12,2 Kb/s) to high rate packet data service (up to 2 Mb/s). Two access schemes are defined, W-CDMA (Wideband CDMA) which adopts frequency division duplexing (FDD), and TD-CDMA (Time Division and Code Division Multiple Access) which is based on time division duplexing (TDD), to be used respectively in the paired part of the spectrum assigned to UMTS, 60 MHz from 1920 to 1980 MHz (uplink) and 60 MHz from 2110 to 2170 MHz (downlink), and in the unpaired part, 35 MHz from 1900 to 1920 MHz and from 2010 to 2025 MHz, respectively.

The UMTS standardization bodies have designed a radio interface highly flexible able to provide different bearer services with different bit rates and different transfer modes. For example, circuit switched and packet switched transfer modes are available. Within each transfer mode different quality of service can be achieved by suitably setting physical layer parameters such as the spreading factors (SF) of the physical channels, the rate of the FEC (Forward Error Correction) code used to protect information bits, the target SIR of the power control procedure and the ARQ (Automatic Repeat reQuest) scheme [3].

The evaluation of the performance of UMTS radio access network in a single service scenario is a widely discussed topic in the literature. However, few works have appeared up to now which aim at analyzing the UMTS system with mixed traffic scenarios [4] [5]. In [6] we have evaluated the impact of some choices on the configuration of UMTS W-CDMA radio interface, when considering packet service only with web-browsing traffic. It has been proved that the settings of the physical layer parameters has a deep impact on the performance of the radio interface.

Regarding the multimedia service scenario, 3G operators have to decide weather to reserve different frequency carriers to different services or to share a single frequency carrier between different services. In this second case, when different services contend for the shared resource, their performance characteristics may highly change from the single service case. Therefore, an exhaustive analysis of the radio interface performance is of utmost importance, and can give useful insights to the 3G operators on how to exploit effectively the radio resources [7].

In this paper we evaluate the performance of a mixed traffic scenario on the downlink of UMTS W-CDMA, where speech traffic and web–browsing traffic share the same frequency carrier. The paper is organized as follows. In Section II we give a short overview of the basic characteristics of UMTS radio interface, and we present the system model adopted for simulations. In Section III we present and discuss the results obtained for voice and data service, while in section IV we evaluate the system capacity with mixed traffic. Finally, section V includes our concluding remarks.

II. Real System and Simulated Model

A. UMTS radio interface overview

The W-CDMA access scheme of UMTS adopts a chip rate of $3,84$ Mchip/s. It presents a carrier separation of 5 MHz, so that up to 12 carriers can be defined in the available bandwidth.

At the air interface, the physical layer offers a transport service to higher layers through physical channels. The upper layer information is first protected by the physical layer using FEC codes and then it is spread and modulated with a constant chip rate. The spreading process is based on two codes, namely the spreading code and the scrambling code. The spreading code increases the flow bit rate to the chip rate of the air interface according to the Spreading Factor (SF), instead the scrambling code shuffles the transmitted chip sequence.

Physical channels are defined by the associated spreading and scrambling codes. The bit flow is divided into time-slots, 666 μs

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long. Transport channels are mapped into the physical channel by the physical layer [8].

Transport channels are divided into dedicated channels, which can be assigned and then used only for transmissions to/from a single mobile terminal (MT) at a time, and common channels which are time shared by different MTs. Speech traffic is transported over dedicated channels. Dedicated Channels (DCH) are assigned to single users through set-up and tear down procedures and are power controlled according to a closed loop mechanism that adjusts transmission power in order to keep the SIR (Signal-to-Interference-Ratio) at a target value.

As far as the packet switched traffic is concerned, different transfer mode are available. Packet data can be delivered using a circuit oriented scheme which still adopts dedicated channels, or can be delivered using ad-hoc shared resources. In particular, two different shared channels are available for packet transmissions: DSCH (Downlink Shared Channel) and FACH (Forward Access Channel). To access the DSCH users must have an associated active DCH on the downlink whose power control mechanism is also used to control the power of the shared channel itself. The FACH is shared by many users to transmit short bursts of data, but, unlike DSCH, no closed-loop power control is exerted and no DCH must be activated to access this channel.

B. Simulation Model

In our model, speech traffic at 12,2 Kb/s is delivered on the downlink over dedicated channels (DCH) with spreading factor 128, while high bit rate web-browsing sessions share a downlink shared channel (DSCH).

We have considered 49 cells with radius equal to 300m, organized in a wrap-around domain to avoid border effects in the interference calculation. Each cell has an omni-directional antenna with unit gain located at the center.

The received power P_r of the generic downlink transmission (both data and speech) is given by [9]: $P_r = P_t 10^{\frac{\epsilon}{10}} L$, where P_t is the transmitted power, L is the path loss, $10^{\frac{\epsilon}{10}}$ accounts for the loss due to slow shadowing, ϵ being a normal random variable with zero mean and σ^2 variance. We assume a path loss L expressed as: $10 \log L = -(128.1 + 37.6 \log r)\,(dB)$, where r (in kilometers) represents the distance between the mobile and the base station. The shadowing standard deviation is equal to 5 dB. The generic user is assigned to the BS with the minimum radio attenuation.

At the receiving side, the SIR is evaluated for each transmission as

$$SIR = \frac{P_r \times SF}{\alpha I_{intra} + I_{inter} + P_N} \qquad (1)$$

where SF is the spreading factor of the physical connection, P_N is the thermal noise assumed equal to -99 dBm, I_{inter} is the sum of the signal powers received from the other cells, I_{intra} is the sum of the signal powers received from other users in the same cell, and α is the loss-of-orthogonality factor due to the multipath that, according to [10], is assumed equal to 0.4.

The calculated SIR value is used to test correctness of the transmission on the basis of the BLER vs SIR curves obtained through link level simulation used in [6]. As to packet switched traffic, our simulator assumes an ideal ARQ procedure, i.e. the transmitted block is kept in the transmitting queue in case of error and is canceled otherwise. Obviously retransmission is not applied to speech traffic. Voice information bits and data information bits are protected using convolutional codes with rate respectively equal to 1/3 and 1/2.

The dedicated channels are subject to a typical closed loop power control procedure. The mobile terminal requests the base station for a transmitting power update in order to track the SIR fluctuations. The power transmitted on each downlink traffic channel can not exceed the value of 30 dBm, whereas the overall power transmitted by a base station is limited to 43 dBm [10].

The birth of a voice calls in the system is modeled with a Poisson point process of intensity λ_v. Each call remains active for a period of time which is exponentially distributed with mean 60 seconds. We have used an always on model for the voice calls, i.e., no silence suppression technique is implemented at this stage of analysis. Once the call ends up, the voice user exits the system. We have implemented a hard call admission control on the voice calls, which aims to limit the number of active calls in each cell to a given value (N). All the results presented in this paper are obtained offering to each cell a high voice load, high λ_v, and applying the hard call admission described above so that the average number of active calls per cell is set to N.

Similarly the arrive of packet users in the system is modeled with a Poisson point process of intensity λ_d [9]. Each new user requests the download of a web-page which is modeled by a flow of packets whose number is geometrically distributed with mean $N_p = 25$. The packet length is negative exponentially distributed with mean 3840 bits.

The position of a new user, either voice or data, is uniformly selected in the service domain.

III. Performance of Voice and Data Services

In this section we analyze the performance of W-CDMA UMTS radio access interface when providing access to voice and data users. The quality of voice calls is mainly evaluated through the measured Block Error Rate (BLER), while data traffic performance is analyzed using the average packet delivery delay and the throughput.

All the presented results have been obtained running steady-state simulations 900 seconds long. The first 100 seconds are used as warm-up time, that is to say the statistical results collected during this period are neglected. The remaining 800 seconds are divided into 4 simulation runs. During each run the results are collected and used to calculate one sample of each statistical quantity used for evaluation. The output results have been tested according to the t-student statistical test. For all the measures reported in the following (throughput, BLER, etc) the confidence interval is under the 5%, given a confidence level of 95%.

Figure 1 shows the BLER versus the SIR target value for several numbers of voice calls accepted in each cell. No data traffic is considered in this case. As in data service over shared channel [6], the optimal value of SIR target comes from a trade-off. If a too small SIR target is chosen too many errors occur since the code

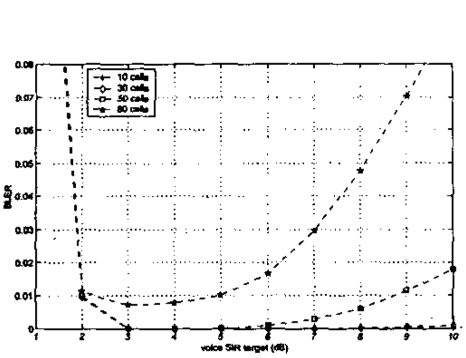

Fig. 1. *Block Error Rate vs. SIR target value for different numbers of voice users per cell. No active data users.*

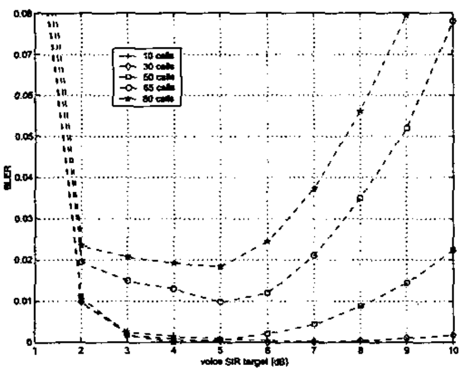

Fig. 2. *Block Error Rate vs. SIR target value for different numbers of voice users per cell. 10 data users sharing a SF=4 DSCH.*

protection is useless. On the other side, with a high SIR target the power requirement increases and too many transmissions tend to be driven into saturation. We observe that for almost all the cases considered the SIR target value around 3 dB provides the lowest BLER. With such a SIR target value, up to 80 voice users per cell can be served with a BLER lower than 1%.

When assuming 10 data users sharing a SF= 4 DSCH and an offered data traffic per cell of 100 Kb/s, the BLER vs the SIR target of voice users curves are reported in figure 2 for several numbers of active voice calls, . We observe that the presence of data traffic limits the capacity of voice, which, assuming a target BLER under 1%, is now reduced to 65 calls per cell. Furthermore, the SIR target value which provides the lowest BLER is 5 dB for all the numbers of voice calls per cell, 2 dB higher than the optimal value of SIR target found in the case of voice traffic only. This is due to the burstiness of data traffic which increases the fluctuations of the interference. The interference standard deviation versus the number of voice users is plotted in figure 3 for the two cases with and without data traffic. As expected, the interference has a higher standard deviation in the case of mixed traffic, therefore the power control cannot easily track interference variations and an higher value of SIR target is needed in order to prevent the SIR fluctuations from affecting the BLER of voice calls. We have obtained very similar results with different number of data users and we have observed that system performance basically depends on the intensity of data traffic rather than on the number of users generating this traffic.

Figure 4 shows the average packet delivery delay versus the

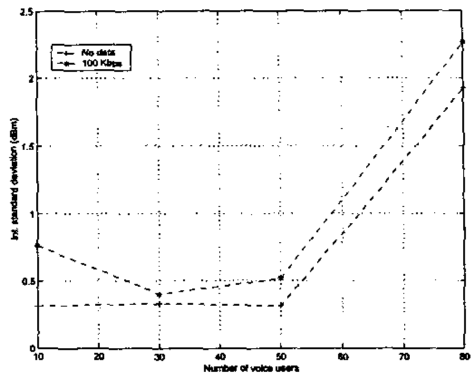

Fig. 3. *Interference standard deviation vs number of voice users in the cases of no active data users and 10 active data users generating 100 Kb/s traffic per cell.*

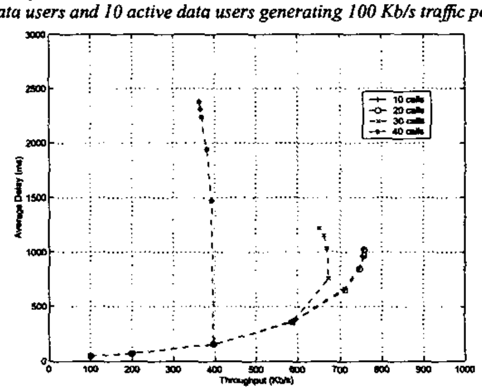

Fig. 4. *Average delay vs throughput of data users with different numbers of voice users per cell.*

throughput of one SF=4 DSCH shared by 10 data users, for several numbers of voice users active in the same cell. The performance of the downlink shared channel is obviously affected by the presence of voice calls interference, and drops dramatically if the number of voice users grows above 30.

Figure 5 reports the BLER of voice calls vs the number of voice users per cell, when varying the data offered load. Unexpectedly, we observe that if the offered data load is low (200,400 Kb/s), the voice BLER decreases when increasing the number of voice users per cell, that is when increasing the average value of the interference. Such a behavior is explained by the fact that two different interference sources exist in the system: voice calls and web-browsing sessions. The interference generated by the former is slowly time varying, while the one generated by the latter is characterized by rapid fluctuations in power levels. If the amount of the slowly varying part of the overall interference is increased, the standard deviation of the overall interference decreases, and consequently the power control procedure can track interference fluctuations in a more effective way and the BLER decreases.

However, for high data traffic loads (600,800 Kb/s), the voice BLER has a minimum with respect to the number of voice users per cell (figure 5). After that point, the voice BLER starts increasing. This behavior is due to the power limits: even if the interference standard deviation decreases, its mean value increases when growing the number of active calls per cell; the transmis-

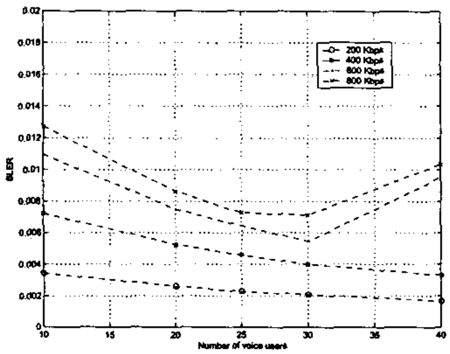

Fig. 5. *BLER of voice calls vs number of voice users when varying the data offered load.*

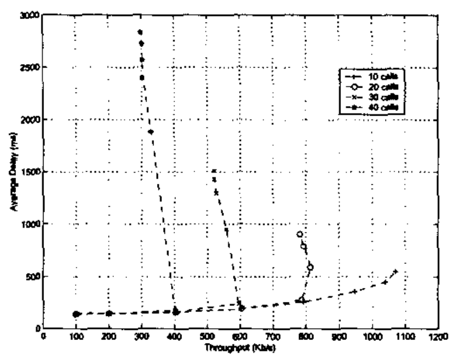

Fig. 6. *Average delay vs throughput of data users with different numbers of voice users per cell when using 3 SF=8 DSCH per cell.*

sion power is adjusted to keep the SIR at the target value. If the transmission power limit is reached, the SIR starts decreasing and the BLER starts increasing. The curves of the fraction of transmissions performed at the maximum power confirm this behavior, but these curves are not reported for the sake of brevity.

In [6] we found that the optimal performance in terms of maximum throughput of the system, when serving data users only, is achieved using multiple SF= 8 DSCH per cell. The curves of average packet delivery delay versus the throughput for the same data traffic configuration in a mixed traffic scenario with three SF= 8 physical DSCH per cell are reported in figure 6. As in the case of one single SF= 4 channel per cell (see figure 4), the performance of the data transfer over DSCH is highly affected by the interference generated by voice users. As a matter of fact, if the number of voice users grows the throughput of data service is lowered.

Regarding the quality of the voice calls in the same configuration, figure 7 reports the BLER of voise calls vs the number of voice users per cell, when varying the data offered load on the three SF= 8 DSCH. At low data loads (200,400 Kb/s), the BLER is lower than the one measured in the configuration with one SF=4 DSCH. The use of slower channels, SF= 8 instead of SF= 4, doubles the average data transmission period. Longer transmissions generate a smoother interference profile characterized by a lower standard deviation and therefore the closed loop power control can more effectively cope with interference fluctuations, providing a

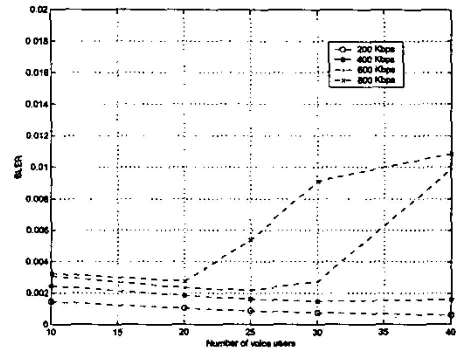

Fig. 7. *BLER of voice calls vs number of voice users when varying the data offered load when using 3 SF=8 DSCH per cell.*

better BLER. On the contrary, at high loads (600,800 Kb/s) all the three available DSCHs are fully occupied by data traffic. In this situation the average interference level is too high and the power control tends to drive into saturation the voice calls with a consequent higher experimented BLER. If we fix the target BLER to 1% and the data users load to 800 Kb/s, up to 35 voice calls can be served in the configuration using three SF= 8 channels with respect to the 40 voice calls served in the case of one SF=4 DSCH (see figure 4). A similar behavior has been observed if allowing the use of four physical DSCHs per cell.

IV. System capacity with mixed traffic

Once acquired some insights on the effects on the performance of the system with mixed traffic, in the following we aim at defining the system capacity in such a traffic scenario. We call system capacity the maximum total voice and data throughput which fulfills the QoS requirements given below on voice and data traffic.

In our simulations, voice and data traffic refer to two different QoS requirements: voice must be delivered with an average BLER not exceeding a target value, 10^{-2}, while data blocks are delivered with no error and with an average delay not exceeding 500 ms. For N active voice calls per cell, the system capacity is obtained by increasing data traffic in all the physical configurations (2, 3, 4 DSCH with SF= 8) until either the delay constraint or the voice BLER constraint is exceeded. In this case the capacity is given by the sum of voice throughput (N*12,2 Kb/s) and the maximum data throughput achieved.

Figure 8 shows the maximum values of the data throughput and the voice throughput which fulfill the QoS requirements given above, when using the three physical configurations with 2, 3, 4 SF= 8 channels per cell. The system capacity is obtained by taking the best points of the three curves.

The results of such an investigations are summarized in Figure 9, where the maximum total voice and data throughput versus voice throughput is represented by the solid line.

Two main observations come from this figure. First, the system capacity with data only is 1250 kb/s, 25% higher than that with voice only, 976 kb/s, corresponding to 80 voice calls per cell. Voice circuits require a very low BLER value all the time and, therefore, they must be always granted the power needed to reach the corresponding SIR target. As more users are added, the

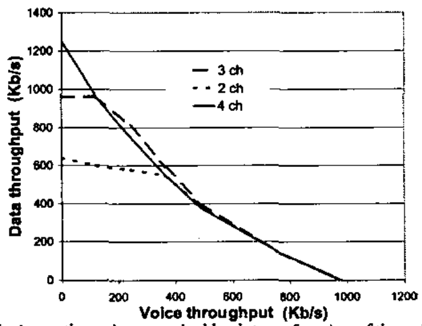

Fig. 8. *Maximum throughput reached by data as function of the voice throughput, when using 2, 3, and 4 channels with SF=8 and R=1/2.*

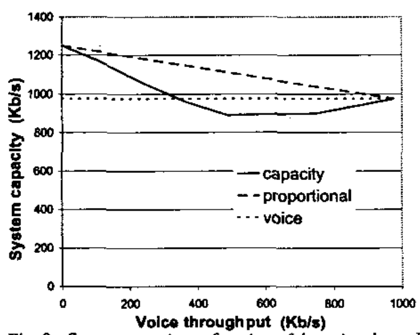

Fig. 9. *System capacity as function of the voice throughput.*

required power increases until some users reaches the maximum allowed value. The number of users admitted at this point represents the system instantaneous capacity (IC).

Similarly, we can define the IC for data as the maximum data throughput allowed in a frame in static conditions. Data transmissions can operate temporarily beyond capacity, i.e. even if the required power is not available, since they can take advantage from retransmission. As a matter of fact, the highest data throughput is observed with a BLER on the channel as high as 10%. In other words data can take advantage of interference fluctuations more effectively than voice.

The second observation is that the system capacity reduces when mixing voice and data. In fact, the capacity line in Figure 9 is always below the "proportional" line, that is the capacity of the ideal case where mixing traffic does not affect efficiency. The proportional line is given by the straight line that connects the voice alone and data alone capacities.

Furthermore, we observe that, when adding data, the capacity decreases from the voice only point, i.e., below the "voice" line, that represents the capacity if data performed exactly as voice. Therefore, adding a certain load of data traffic requires to drop an higher load of voice traffic. This behavior is due to the fact that the accuracy of the close-loop power control mechanism is impaired by the burstiness of data.

V. Conclusions

In this paper we used detailed simulations to evaluate the performance of W-CDMA UMTS radio interface when providing access to speech and data users . The results show that if no data traffic is considered up to 80 voice calls per cell can be served with a BLER around 1%, by properly setting the target SIR of the closed loop power control procedure. If additional data traffic is considered in each cell, the capacity of the voice service decreases and the value of the optimal voice SIR target is increased because of the increased burstiness of the interference level. Furthermore, the interference generated by the voice calls limits the capacity of data service in terms of maximum throughput both in the configuration using one single DSCH per cell, and in the configuration where the use of multiple DSCH is allowed. Finally, we defined the capacity in the mixed traffic scenario and shown that this capacity is lower with respect to the one of a single traffic scenario.

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