Impact of data traffic composition on GPRS performance

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Abstract: The topic of this paper is the evaluation of the impact of data traffic composition on GPRS performance. A detailed statistical analysis of GPRS traffic per service at different levels has been carried on live measurements. A multi-service performance model is presented in order to derive simple and closed form formulas, associating capacity, traffic characteristics and performance. This performance model allows the analysis of the impact of a mix of the applications (WAP, Web, e-mail, etc…) on the quality of service QoS offered to GPRS users. It also gives the opportunity to evaluate the impact of the introduction of new services on the QoS offered to already existing services.

Keywords: traffic model, GPRS, live measurement, processor sharing, performance model

1. INTRODUCTION

The main challenge in the engineering of a multi-service mobile network is the integration and support of a wide variety of services such as WAP, MMS, Web, e-mail, etc. These data services require different levels of quality of service (QoS). Moreover the traffic corresponding to each service is highly bursty and can be characterized by a typical ON/OFF process [5]. The total traffic generated by data users is consequently highly dependent on the burstiness of each service. Optimal dimensioning of this multi-service network requires the knowledge of the traffic characteristics of each service.

The expected merge of the wireline and the wireless Internet implies that a dramatic change will occur in traffic composition within mobile networks. For example, Web traffic will probably overflow WAP traffic. Indeed, HTML compatible browsers will soon be widely available in mobile handsets. And the most popular wireless application WAP will emerge towards TCP, following WAP 2.0, and will show characteristics similar to the Web service.

In order to analyze how the content of the applications mix (e.g. WAP, Web) impacts the QoS of the GPRS networks, and also to evaluate the impact of the introduction of a new service on the performance of existing services, we have developed a multi-service performance model. This model relies on an ON/OFF model for each service. It requires a realistic characterization of the duration of the OFF-period and of the size of the ON-period.

That is why a traffic characterization has been carried out on live traces of the Orange GPRS network. The analysis of these live measurements was conducted at different levels (packet level and flow level) for various services supported by GPRS. Even though Internet traffic characterization has been a subject of interest for many years, very few results have been published to date on traffic characterization for wireless networks. Existing works

mainly focus on a packet level characterization of wireline Internet traffic, and especially on the well-known self-similar properties of the traffic on that level [11, 7]. Recently, much attention has been given to higher-level traffic characterization like flow [9] or session [8].

The goal of this paper is twofold. The first goal is to provide a realistic multi-service traffic model that is based on the statistical analysis of GPRS traffic traces measured on a live operational network. The second goal is to present an insensitive multi-service performance model for GPRS data traffic, that will be fed by the average multi-service traffic parameters (flow size and think-time averages) obtained by our statistical analysis. Moreover, a traffic characterization study was also the opportunity to analyze the impact of protocols (TCP, WTP, PPPoE, etc) on the characteristics of the traffic transmitted on the access network.

The rest of the paper is organized as follows. Section 2 deals with the composition of GPRS traffic in terms of transport protocols and in terms of service types. Traffic characterization at packet and flow level is developed in section 3: packet size distribution is studied for each service type, as well as flow size distribution (in bytes) and think-time distribution (in seconds) for each service type. In section 4 we present a multi-service performance model for GPRS and we give closed form formulas for the average performance for each service type. Section 5 is an evaluation of the QoS offered for each service type, under various traffic mix scenarios. Finally, section 6 gives a conclusion.

2. DATA TRAFFIC COMPOSITION IN GPRS NETWORKS

In this section, we present the different protocols employed by GPRS to ensure end-to-end applications. We also give traffic composition per TCP (or UDP) applications and IP protocol in terms of bytes, packets and flows in downlink and uplink traffic. The statistical results presented are realized on live GPRS measurements.

2.1. GPRS services and applications

GPRS can act as a packet wireless access to existing Internet services, notably using the WAP protocol, and offers new wireless services, such as MMS. Several protocols were defined to route data packets between the different network nodes according to the nature of their traffic. These protocols are WSP and WTP (over UDP) for WAP or MMS services; HTTP (over TCP) and DNS (over UDP) for Web navigation; POP3, SNMP (over TCP) for e-mail reception and SMTP for e-mail sending; FTP (over TCP) for file transfers. Unlike TCP, the UDP protocol ensures short transfer time but is less reliable. Several protocols were set up for GPRS systems to ensure the reliability of services using UDP (e.g. WSP, WTP,…)[10].

Among the new GPRS packet services, there is the packet switched (PS) WAP. This service has the same operation mode as the Web; it uses WML which is a markup language similar to HTML. Like the Web service, when a user wants to access a WAP site, he sends a WSP and WTP request which will be translated by a WAP gateway (located between the GGSN and the WAP/Web server) into a HTTP request. The server receives and interprets the request and then sends information directly either in WML to the gateway, or through an HTML filter which translates it into WML in order to be redirected to the user [10].

Unlike Web pages, WAP pages (called decks) are very small in size, about 1400 bytes (the WAP packet size is then usually limited to 1400 bytes). A deck comprises one or multiple objects (called cards), which have an average size of about 500 bytes.

2.2. Live traffic measurements

Few works have been published about multi-service wireless networks. Thus most existing performance models are based on wireline measurements. A characterization of

traffic patterns for each service is required in order to ensure an optimal dimensioning of GPRS networks. Understanding the nature of GPRS data traffic requires the knowledge of the protocols employed to support a given service.

That is why we have investigated GPRS data traces collected on the live Orange France GPRS network. The measurements were collected on two different G_b interfaces during a ten day period in July 2004 (about 5 hours per day, between 11 a.m and 4 p.m). The frames captured at the G_b interface contain the TCP or UDP/IP header information (packet size, port numbers, transfer direction, etc) and a timestamp which indicates the arrival time of packets with an accuracy of one millisecond.

This information allows the characterization of data traffic at different levels: packet, flow, ON-period and session. The main parameter of GPRS dimensioning is the Temporary Block Flow (TBF) throughput which is defined as the ratio between the data volume carried by a TBF and the time taken in transfer. In this study, we assume that the data transferred during an ON-period will be carried by a TBF, and the think-time is the interval time between two consecutive TBFs

A TBF corresponds to a group of packets such that the IP packet inter-arrival time is below the Keep Alive Timer (KAT). A more accurate distinction of the organization of the packets in a TBF can be achieved by separating the packets with the help of a 5-tuple {*IP protocol, IP source address, IP destination address, source port number, destination port number*}. Then a flow here will be a group of packets with an inter-arrival time below the KAT and with the same 5-tuple identifier.

WAP browsing and MMS services both use the WAP protocol. But as the recommended maximum size of a deck for the WAP is 1400 bytes and if we assume that a single deck is transferred per ON-period for WAP browsing, WAP browsing and MMS services can then be separated with the help of the ON period volume.

2.3. Protocol composition

Table 1 reveals the composition of the traffic per IP protocol in terms of bytes, flows and packets in uplink and downlink traffic. Unlike the wireline Internet where TCP is the most dominant traffic, Table 1 shows UDP's dominance over the mixed data traffic observed in GPRS. UDP averages at about 67% of the bytes, 65% of the packets, and 80% of the flows. TCP only represents about 30% of the bytes, 35 % of the packets, and 20% of the flows. The other IP protocols (IPv6, ICMP, etc), labeled "Other", represent a negligible percentage of the overall traffic (the port numbers only exist if TCP or UDP is used).

Table 1. Traffic composition by protocol

Protocol	bytes	byte DL	byte UL	flows	flow DL	flow UL	packets	packet DL	packet UL
TCP	31%	82%	18%	20%	49%	51%	35%	48%	52%
UDP	67%	79%	21%	80%	47%	53%	65%	39%	61%
Other	2%	65%	35%						

Like the wireline Internet, wireless traffic in terms of volume is asymmetric and is mainly downlink. The data loading direction is from the server towards the subscriber. About 80% of TCP/UDP traffic is in this direction. The uplink traffic is generally composed of requests, acknowledgements and control packets, and it represents about 20% of the volume.

TCP traffic is balanced on both links in terms of packets, but UDP traffic is predominant on the uplink. That is due to the use of higher-level protocols such as WSP and WTP on UDP. We also consider the DNS requests which are also transferred over UDP.

2.4. Application composition

As mentioned in the previous paragraph, UDP is dominant in GPRS data traffic. This is due to the high use of PS WAP and MMS services. Indeed, current mobile handsets mainly have a WAP browser and MMS capabilities. WAP browsers already existed in CSD and HSCSD modes, and MMS service usage is rapidly increasing. Popular services like logos and ring tones also use WAP. HTML and e-mail compatible mobile handsets as well as laptops equipped with a GPRS data card are not yet widely used; this may partly explain the relatively low usage of HTML and e-mail services in current GPRS networks. In the rest of the paper, we separate the WAP traffic between WAP browsing and all other services, such as MMS, logos and ring tones, carried by the WAP protocol (also using port 9201).

Table 2. Traffic asymetry by application

Application	byte DL	byte UL	flow DL	flow UL	packet DL	packet UL
WAP	72 %	28 %	50 %	50 %	38 %	62 %
Other WAP	86 %	14 %	50 %	50 %	40 %	60 %
HTTP	82 %	18 %	50 %	50 %	48 %	52 %
E-mail send	6 %	94 %	42 %	58 %	47 %	53 %
E-mail recv	91 %	9 %	48 %	52 %	50 %	50 %
Other	78 %	21 %	40 %	60 %	50 %	50 %

Table 2 shows the traffic composition per application in terms of volume and packets in both transfer directions. We present only the most usual services like WAP, Web and e-mails. The services named "Other" group all the other services. It is observed that WAP and Web services have a different asymmetry for the volume of traffic and the number of packets.

3. TRAFFIC CHARACTERIZATION

The analysis of data traffic can be achieved on three scales corresponding to three entities: packet-level which is the elementary quantity carried by the network, flow-level which is a sequence of packets associated with a single instance of an application, and session-level which is a succession of flows for a given application. Flows belonging to two consecutive ON-periods are separated by a think-time. Figure 1 shows the different time scales of our statistical analysis. The mini-OFF time presents the inter-flow time in the ON-period which is limited by the KAT that is used to artificially maintain a TBF allocated for successive data transmissions.

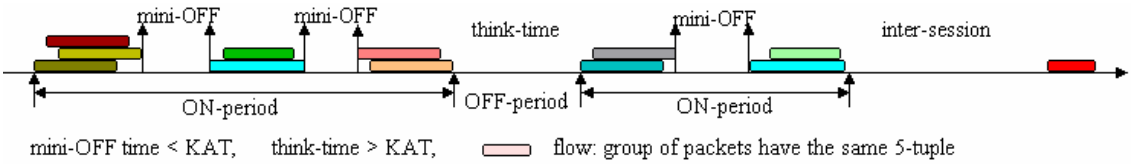


Figure 1. Different time scales of data traffic

3.1. Packet-Level Characterization

IP packet size in data traffic is very changeable. It is different for different transport protocols and according to the transfer direction. Figure 2 depicts the cumulative distribution function (CDF) of the packet size in the GPRS traffic studied. As can be seen, the TCP "downlink" curve has typical distinct steps at 40, 576 and 1500 bytes. It is similar to the curves obtained for wireline networks. However, the UDP "downlink" curve is very smooth

and has a typical step at 1420 bytes, which is the MTU size of WAP packets. To perform an analysis for each service, we present figure 3 giving the packet size CDF by application.

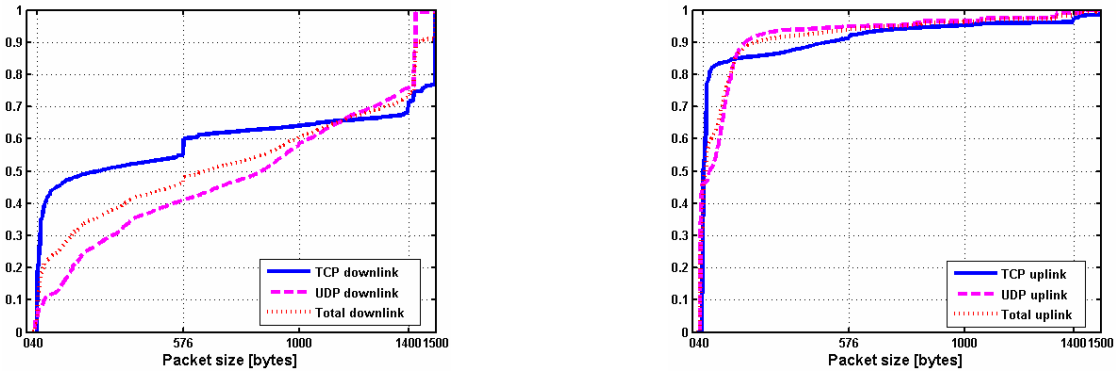


Figure 2. Packet size CDF per protocol in downlink (left) and uplink (right) traffic

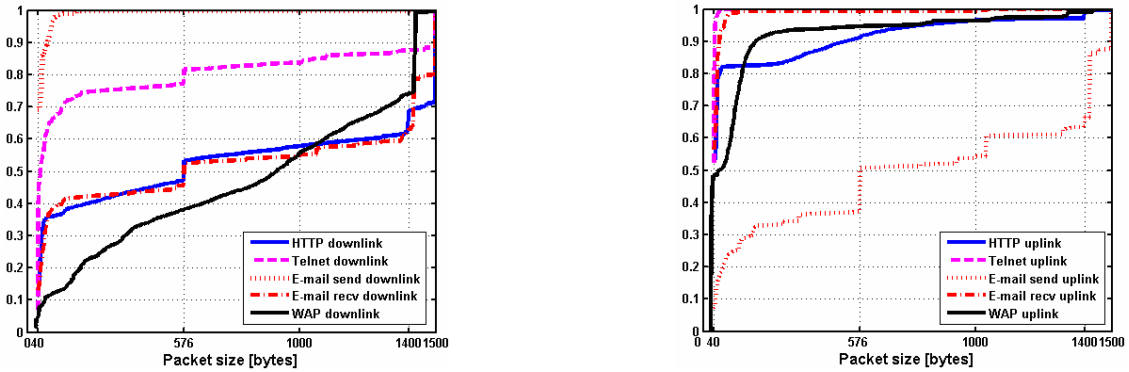


Figure 3. Packet size CDF per application in downlink (left) and uplink (right).

Downlink traffic: for TCP Applications, we observe a distinct step at around 40-44 bytes. These correspond to acknowledgement and control packets like SYN, FIN, RST. A second step at around 576 corresponds to the default TCP MTU size. Several packets have a size between 1420 and 1492 bytes. This last value corresponds to the PPPoE MTU size. The last step at 1500 bytes corresponds to the Ethernet MTU size. This size is adapted for Ethernet and xDSL networks. It is also adapted to the peak throughput offered by GPRS networks.

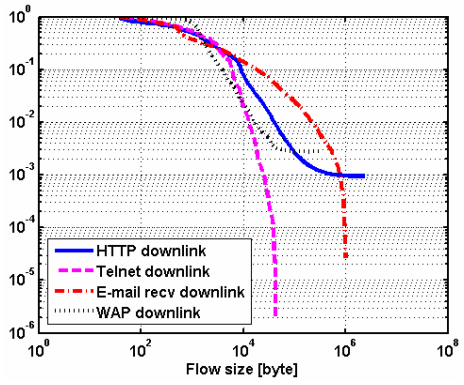
For UDP applications like WAP/MMS, packet sizes are smoothly distributed with a peak for 1400 bytes. This value corresponds to the default size of the WSP SDU. This size also corresponds to a commonly recommended maximum size for decks.

Uplink traffic: for all services, most IP packets are small sized. The packets essentially consist of acknowledgements, controls and requests. The remaining packets correspond to upload traffic for both UDP and TCP. For e-mail traffic we observe a peak at around 1006 bytes corresponding to the SLIP MTU size (Figure 3).

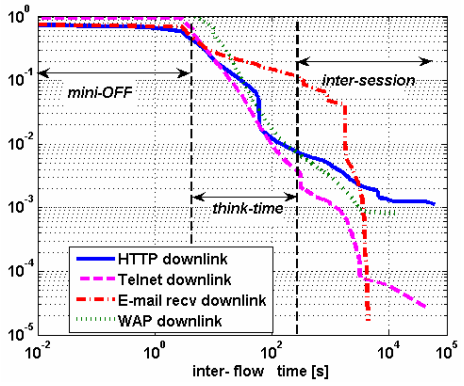
3.2. Flow-Level Characterization

Figures 4 (a) and (b) depict the complimentary CDF (CCDF) of flow size and the inter-flow duration per service respectively. As can be seen in figure 4(a) the distributions of flow size in bytes of HTTP and WAP applications (e-mail and Telnet applications respectively) have similar tail distribution. Several works have characterized these tails by heavy-tailed distributions like log-normal, Weibull and Pareto [9]. In figure 4(b), we can identify the mini-OFF, think-time and inter-session time scales. The inter-flow duration is defined as the

duration between two flows. It is called mini-OFF if the duration is lower than the KAT. If this duration is greater than the KAT then we call it think-time. Lastly, if it is superior to 180s we consider that it is an inter-session. As can be seen from the curves, the distributions of flow size and inter-flow time cannot be represented by a single law. A study in order to find a mixture of laws fitting the whole distribution is in progress.



(a)



(b)

Figure 4. Log-scale plots of (a) flow size CCDF and (b) inter- flow time CCDF.

Figure 5 shows the linear scale plot of WAP and HTTP flow size CDF. As mentioned in §2.4, we distinguish between WAP browsing and all other services carried by the WAP protocol such as MMS, logos, etc. A major part of the WAP flows are small sized, between 30bytes and 1kB which correspond to WAP browsing service. For HTTP and other WAP applications, flow sizes mostly range between 1kB and 10kB. Figure 6 shows the linear scale plot of inter-flow time CCDF for WAP and HTTP applications. As can be seen a large range of times are small, in particular for the Web where the flows of a Web page arrive in parallel.

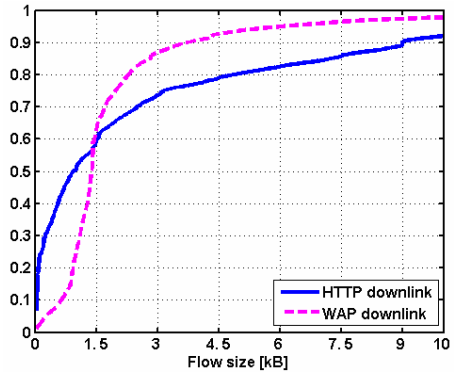


Figure 5. WAP and HTTP flow size CDF

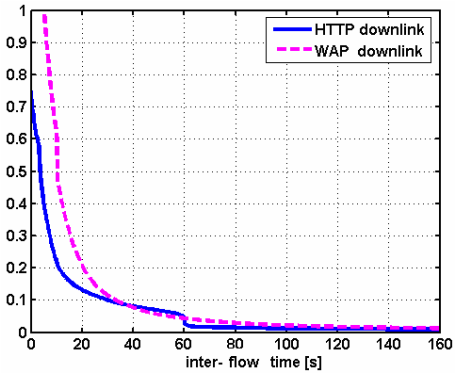


Figure 6. Inter-flow time CCDF

The model developed in [3][4] is insensitive, hence the average performance does not depend on detailed traffic characteristics but only on the average traffic parameters. Thus, the insensitivity property allows us to deal only with the characterization of the average file size and the think time duration. The distribution does not have any impact on the average performance perceived by the end user (see section 4). In table 3, we give details of average traffic parameters for the most commonly-used services, WAP browsing and the Web. Thus, the ON-period for the Web (resp. WAP) has an average size around 17.5kB (resp. 1.1 kB). The think-time was set to 14s (resp. 16.5s). These results are close to results published in [6].

Table 3. Web and WAP browsing parameters

Web Parameters	Average
Flow size [byte]	4700
Flows per page	3.7
Pages per Session	6.5
Page inter-arrival time [s]	14

WAP Parameters	Average
Card size [bytes]	500
Decks per session	16.5
Deck size [bytes]	1100
Deck inter-arrival time [s]	16.2

4. PERFORMANCE MULTI-SERVICE MODEL FOR GPRS

A multi-service model has been proposed in [1] for modeling high speed IP access links. A similar approach is used here to obtain a closed form formula to analytically evaluate different performance indicators for GPRS networks.

4.1. Assumptions

In a GPRS system, the basic transmission unit of a PDCH is called a radio block. The structure and the payload size of a radio block depend on the coding scheme. Several PDCHs can be simultaneously used by a mobile to transfer data depending on the multi-slot class of the mobile handset. Nevertheless, each PDCH can carry traffic for more than one connection simultaneously (a GPRS physical connection is called a TBF). Thus, the data transmission rate also depends on the number of GPRS users multiplexed on the same PDCH.

The number of TBFs that a PDCH can have in downlink and uplink depends on the operator's choice. Each TBF is identified by a TFI of 5 bits length which limits the number of simultaneous GPRS connections to 32 per TDMA. Thus, the maximum number $n_{\max}$ of data users in active transfer (active TBF) depends on the number of channels (C_d) reserved as PDCH for GPRS, and is limited by the maximum number m of users that can use a single time-slot and the number of TFIs per TDMA (i.e., $n_{\max} = \min(32, m\, C_d)$).

We assume that a fixed number N of GPRS users in the cell generates ON/OFF traffic, and that all GPRS customers have the same multi-slot capabilities "d+u" where d and u are the numbers of time-slots that can be simultaneously used for the downlink and uplink traffic. Most customers have "d = 4 or 3" multi-slot capability in downlink and "u = 1 or 2" in uplink. We focus only on resources employed for the downlink because the nature of data traffic is asymmetric and it is mostly downlink (Table 1 § 3.3).

As the maximum number of time-slots per user is d, $s = \lfloor C_d / d \rfloor$ is the maximum number of active users if the radio resource manager allocates d time-slots for each one. If the number of users in active transfer is lower than s, each user has d time-slots. Therefore, each one receives a service with rate ($d\ \mu_{GPRS}$) where the data rate μ_{GPRS} per time-slot depends on the coding scheme used (μ_{GPRS} (kb/s) = 9.05 for CS1, 13.4 for CS 2, 15.6 for CS3 and 21.4 for CS4). A fair sharing of total bandwidth is applied for all active users in transfer when the maximum number of time-slots cannot be allocated to all active users. When the number of active users is greater than s, then each active user receives a service with the rate ($C_d \mu_{GPRS} / j$) where j is the number of users in active transfer.

This bandwidth sharing model can be recognized as the *generalized processor sharing* model considered by J.Cohen [2]. An interesting result of this model is that the stationary distribution of the stochastic process describing the number of active users in progress does not depend on any traffic characteristics except the averages; it depends only on the average of the ON-period and of the OFF-period. This is known as the *insensitivity property* which allows us to express the average performance only in terms of the average parameters.

4.2. Multi-service model

In [3] we developed a basic model for the performance evaluation of GSM/GPRS systems. In this first model all GPRS users use the same application. In this section, we extend our basic model in order to take into account different types of traffic. In principle, several types of traffic such as WAP, Web, MMS, e-mail, etc. with different ON/OFF distributions have to be supported by GPRS networks. In what follows, M will be the total number of different traffic types. Each GPRS traffic type has its own general distribution. $E[\sigma_k]$ will be the average value for the ON-period size and $E[\tau_k]$ will be the average value for the OFF-period duration for a traffic of type-k, $k = 1,\ldots,M$. Because of the insensitivity property, the results are the same even if each traffic type has exponential distributions with mean 1 for the ON-period size and with mean $A_k^{-1}=E[\tau_k]/E[\sigma_k]$ for the OFF-period duration.

We assume that there is a fixed number N_k of GPRS users generating traffic with type-k ($N=N_1+\ldots+N_M$). Under the assumptions of section 2.1, the system can be modeled as an M-dimensional birth-and-death Markov process, with vector $\vec{j}=(j_1, j_2, ..., j_M)$ representing the state of the system, i.e., the number of active users for all service types in the cell at a given time. The steady-state probability of this system is obtained by solving the steady-state equilibrium equations, and it is given by the following closed product-form [4]:

$$p(\vec{j}) = p(\vec{0})\prod_{k=1}^{M} C_{N_k}^{j_k}\,\rho_k^{\,j_k}\prod_{i=1}^{j_1+\ldots+j_M}\frac{i}{\min(id, C_d)}\,, \qquad (1)$$

for all "feasible" states $\vec{j}$ in $\Xi=\left\{\vec{j}=(j_1,...,j_M)/\quad 0\le j_i\le N_i,\ i=1,...,M \text{ and } 0\le j_1+...+j_M\le n_{\max}\right\}$, $\rho_k = A_k\mu_{GPRS}^{-1}$ and $p(\vec{0})$ is obtained by the usual normalization condition. Note that this distribution depends on the traffic parameters ($E[\sigma_k]$,$E[\tau_k]$) only through the ratio $E[\sigma_k]/E[\tau_k]$.

4.3. Average performance evaluation

The GPRS user perceives performance essentially through the average time necessary to transfer a document, this time depending on the size of the document and the average throughput obtained by the user. In this section, we evaluate performance in terms of throughput available for each user in active transfer and blocking probability.

Let $T_{ON,i}$ be the average time taken by the network to complete the delivery of an ON-period of type-i. According to Little's law, the average number of active users ($E[J_i]$) is equal to the product of the average aggregated throughput (X_{T_i}) with the average time $T_{ON,i}$. Thus,

$$T_{ON,i} = \frac{E[J_i]\,E[\sigma_i]}{X_{T_i}} = \frac{\sum_{\vec{j}\in\Xi} j_i\ p(\vec{j})}{\sum_{\vec{j}\in\Xi-\{\vec{0}\}} p(\vec{j})\ j_i\ \min(d, C_d/j_1+...+j_M)\mu_{GPRS}}\,E[\sigma_i], \qquad (2)$$

and therefore, the average throughput X_{C_d,N_i} obtained by each type-i user in active transfer is:

$$X_{C_d,N_i} = \frac{E[\sigma_i]}{T_{ON,i}} = \frac{\sum_{\vec{j}\in\Xi-\{\vec{0}\}} p(\vec{j})\ j_i\ \min(d, C_d/j_1+...+j_M)}{\sum_{\vec{j}\in\Xi} j_i\ p(\vec{j})}\,\mu_{GPRS}. \qquad (3)$$

Another important performance parameter for GPRS dimensioning is the blocking probability. The arriving GPRS user is accepted to transmit/receive data if a sufficient number of free resources are available, i.e., the number of users in active transfer is lower than n_{max} , otherwise it is blocked. Thus, the blocking probability is the probability that C_d time-slots are being used by n_{max} users among the other (N-1) users. It is given as follows:

$$B_{C_d,N_i} = \frac{(N-n_{\max})p(n_{\max})}{\sum_{\vec{j}\in\Xi}(N_i-j_i)\ p(\vec{j})} = 1-\frac{1}{\rho_i}\frac{\sum_{\vec{j}\in\Xi-\{0,0\}} p(\vec{j})\ j_i \min(d, C_d/j_1+\ldots+j_M)}{\sum_{\vec{j}\in\Xi}(N_i-j_i)\ p(\vec{j})}. \quad (4)$$

Consequently, we obtain the simple and analytical formulas (3) and (4) that could be used for GPRS dimensioning. These formulas request only the characterization of the average ON-period size and of the think-time duration. The distribution does not have an impact on the average performances perceived by the end user.

5. GPRS PERFORMANCE EVOLUTION

Today, a major part of the traffic carried by GPRS is generated by WAP browsing and Web navigation (Table 1 § 2.3). This network can be dimensioned with the performance indicators (formulas (3) and (4)). In this section we evaluate QoS indicators for WAP and Web services in one radio cell (using a single Coding scheme CS-2, 4 fixed PDCHs and m =7) as a function of the total numbers of users in the cell. Figures 7 and 8 show respectively the QoS indicators for a simplified present mix scenario (WAP browsing, Web), 75% of WAP and 25% of Web, and in a possible dramatic change of this composition, e.g., traffic containing 34% of WAP and 66% of Web. Since WAP applications will emerge towards TCP-applications using WAP 2.0, they should show characteristics more similar to the Web.

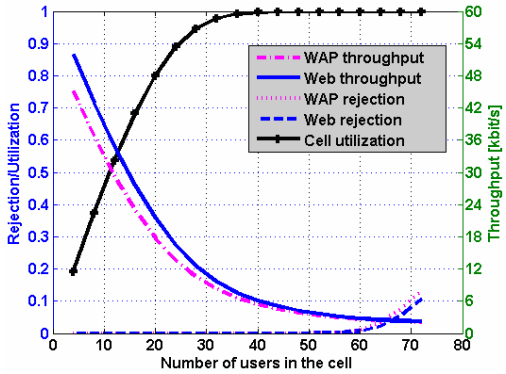


Figure 7. Mix of (WAP (75%), Web (25%))

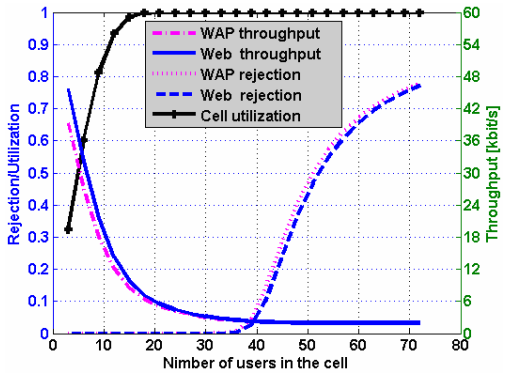


Figure 8. Mix of (WAP (34%), Web (66%)).

From the curve of the first mix scenario, we can observe that as the number of users increases, the average performance slowly degrades. In fact, the total traffic is mainly generated by the WAP users who have a low data volume (ON-period size is about 1kB) to transfer. Thus the TBF duration is short; hence the WAP user finishes his transfer rapidly and releases the radio resource (TBF) rapidly for another user. As a consequence, the blocking probability and radio resource utilization increases slowly when the number of users increases. The average throughput decreases but is not strongly impacted by WAP load (ρ) because the total traffic load is closer to the Web load.

In the second mix scenario, the total traffic is mainly generated by Web users who have a high data quantity to transmit (ON-period size is about 18kB). Thus, the TBF duration is much longer; the Web user occupies the radio resource for a long time. As a consequence, the average performance degrades rapidly when the number of users increases. In this case, the service load has negligible impact on the performance because the radio resource is saturated rapidly; hence all users have the same throughput. This is due to the *GPS* sharing bandwidth.

We can conclude that the system saturation level is strongly dependent on the presence of services with a high ON-period size (e.g. Web service, FTP or a new service like P2P). For several active sessions, the available PDCHs are fully loaded, thus the average throughput decreases rapidly as the number of users' increases. Furthermore, the presence of a service with a high load ρ has a great influence on the performance of other services available in the system, in particular, the services consuming less bandwidth like WAP services.

6. CONCLUSION

In this work we have presented the traffic composition of today's GPRS networks in terms of transport protocol and service types both for uplink and downlink. A realistic traffic characterization per service at different levels has been provided on live measurements of an operational network. We have also presented an insensitive multi-service performance model, which provides a simple relationship between offered data traffic, cell capacity and QoS parameters. Since wireless protocol and services continue to evolve, such a model is essential for an effective optimization of radio resource allocations. It makes it possible to evaluate the users' performances when a dramatic change occurs in the traffic composition, and to predict the impact of the introduction of a new service on the QoS offered to the existing services.

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