An Approach to Mobile IP Traffic Planning

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Abstract—Traffic evaluation is very important for wireless network planning. We should provide enough resources (channels) for conveying the traffic load. Next generation wireless networks are all based on IP. In this path, voice is also handled as VoIP. In this paper considering Eb/No, data rates, source activity factor and other cells interferences in a multi-user system, we first calculate the number of subscribers in a cell, then based on the Markov Model we introduce a queuing model with capacity K and m servers (K>m) suitable for Internet user handling, then we pay attention to traffic calculations for that users and introduce an approach to the IP traffic planning.

Keywords- Mobile systems, Internet Traffic, Erlang.

I. INTRODUCTION

Voice service is no longer the only service in wireless and mobile system. Multiple traffic systems now include voice and data services, or more accurately, many differentiated services with distinctive QoS requirements. Wireless data services include file, video and voice transfer over the mobile networks. Indeed Internet traffic is a combination of the above traffic services. Indeed even within the data services, there are many types of services which have different characteristics and models [1].

In order to use radio resources optimally we need clear and precise models for different services. Services are divided to real time and non-real time services. Voice and peer to peer video communications are examples of the real time traffic [2]. Totally traffic models are based on the statistics characteristics of the services. The model presented in [3] like the 3GPP model presented in [4] uses a multi-layer model for describing sources and in the lowest layer, use Weibull and Pareto distributions for ON and OFF packet durations of Internet traffic respectively. The other model presented in [5] and [6] assigns Log-Normal and Pareto distributions to ON and OFF packet durations of Internet traffic respectively.

Data applications are expected to finally dominate the overall traffic volume [7]. The traffic generated by data applications is inherently bursty and asymmetric, with higher data rates in the downlink than in the uplink [8].

Viterbi in [9] also reviewed the Erlang capacity in a power controlled CDMA system and compared CDMA systems with FDMA and TDMA systems from the capacity point of view.

Internet traffic is bursty and can be modeled as an ON/OFF model. Thus an optimum radio resource management module can transmit traffic information of other users in the empty sections of the bursts. Activity factor which depends on the traffic type and model gives a criterion for the burstiness of the traffic source. [5], [10].

Mobile systems are growing to the Internet based systems, so voice which is the most important challenge must be handled by VoIP techniques. Therefore new radio resource management modules must only handle packet based transactions. Thus a queue is considered in this module that when there is not any resource for transmitting the packets, they will be inserted into it until transmitted in a suitable time. In this paper we consider Internet traffic and voice services. Thus we evaluate the number of traffic users as a function of their Eb/N0 and rates in a multi-cell network with perfect power control in section II. Then we pay attention to the traffic load considerations in sections III, then based on the offered traffic model we constitute new traffic calculations and Erlang D tables in section IV. and finally draw the conclusion.

II. SNIR EVALUATION

For \( i \)th user in a multi-user flat fading channel we express \( Eb/No \) as signal to interference and noise ratio according to:

\[
\frac{E_b}{N_0} = \frac{W s_i}{R_j n}
\]

where \( W \) is the total bandwidth, \( R_j \) the bit rate of the \( i \)th user, \( s_i \) is its power at the receiver and \( n \) is total noise and interference at the receiver [11].

We assume there are \( N \) user groups in reverse link. A user group consists of some users that have the same QoS parameters. One group is for voice service, and the other groups are for various data services for examples ftp and web browsing and etc. We define the power received by the BS as \( S_{v,j} \) for the \( i \)th voice user in the voice user group and \( S_{d,j,n} \) for the other data users in the data user group.
the nth user in the data user group j (j = 1, 2,..., N-1), and define the information data rates as \( R_v \) for the voice user group and \( R_{d_j} \) for the data user group j. For the ith voice user, the received Eb/No is represented as follows [12].

\[
\left( \frac{E_b}{N_0} \right)_{v,i} = \frac{W}{R_v} \sum_{k=1}^{N_v} \alpha_{v,k} S_{v,k} + \sum_{j=1}^{N_d} \sum_{n=1}^{N_{d,j}} \alpha_{d,j,n} S_{v,j,n} + I + \eta_0 W
\]  

(2)

where \( W \) is the bandwidth; \( N_v \) and \( N_{d,j} \) represent the number of users in the voice user group and the data user group j in a sector, respectively; \( \alpha_{v,k} \) is the voice activity factor; \( \alpha_{d,j,n} \) is the data user group j activity factor; \( I \) is the other cell interference; and \( \eta_0 \) is the level of the background noise power spectral density. For the simplicity of the analysis, we assume first that BS uses three ideal directional antennas, and perfect power control. Besides, path loss is proportional to \( 10^{\zeta/10} \) (\( \zeta \) is considered to be a Gaussian random variable and \( r \) is user distance from BS) and fast fading not to affect the power control.

According to the perfect power control, we have \( S_{v,k} = S_v \) and \( S_{d,j,n} = S_{d,j} \) for all \( k \) and \( n \). From the fact that the background noise \( \eta_0 \) can be negligible compared to the user interference, (2) is approximately modified to

\[
\left( \frac{E_b}{N_0} \right)_{v,i} = \frac{W}{R_v} \alpha_v (N_v - 1)S_v + \sum_{j=1}^{N_d} N_{d,j} \alpha_{d,j} S_{d,j} + I
\]  

(3)

Similarly, the received Eb/No for ith data user in the data user group j is

\[
\left( \frac{E_b}{N_0} \right)_{d,j} = \frac{W}{R_{d,j}} \sum_{k=1}^{N_v} \alpha_{v,k} S_{v,k} + \sum_{j=1}^{N_d} \sum_{n=1}^{N_{d,j}} \alpha_{d,j,n} S_{v,j,n} + I + \eta_0 W
\]  

(4)

for \( i = 1, 2,..., N-1 \)

According to the perfect power control, we have \( S_{v,k} = S_v \), \( S_{d,j} = S_{d,j} \) and \( S_{d,j,n} = S_{d,j} \) for all \( k \) and \( n \). From the fact that the background noise \( \eta_0 \) can be negligible compared to the user interference, (4) is approximately modified to

\[
\left( \frac{E_b}{N_0} \right)_{d,j} = \frac{W}{R_{d,j}} \alpha_v N_v S_v + (N_v - 1)\alpha_v S_v + \sum_{j=1}^{N_d} N_{d,j} \alpha_{d,j} S_{d,j} + I
\]  

(5)

After some manipulations on (3) and (5) we have

\[
\{\text{SIR}_v\}^{-1} + \alpha_v \}S_v = \{\text{SIR}_d\}^{-1}_j + \alpha_{d,j} \}S_{d,j}
\]  

(6)

where

\[
\text{SIR}_v = \frac{R_v}{W} \left( \frac{E_b}{N_0} \right)_{v,i} \quad \text{and} \quad \text{SIR}_d = \frac{R_{d,j}}{W} \left( \frac{E_b}{N_0} \right)_{d,j}
\]  

(7)

To satisfy BER requirement which is one of the QoS factors of various services for all the user groups, the received Eb/No should be greater than the required Eb/No i.e.

\[
\left( \frac{E_b}{N_0} \right)_{v,i} \geq \left( \frac{E_b}{N_0} \right)_{v,req} \quad \text{and} \quad \left( \frac{E_b}{N_0} \right)_{d,j} \geq \left( \frac{E_b}{N_0} \right)_{d,j,req}
\]  

(8)

Besides, to satisfy the information data rate requirement for all user groups, the following relations should be satisfied:

\[
R_v \geq R_{v,req}, \quad R_{d,j} \geq R_{d,j,req}
\]  

(9)

After replacing (3) and (5) in (8) and (9) and some manipulation we have

\[
\alpha_v (N_v - 1)S_v + \sum_{j=1}^{N_d} N_{d,j} \alpha_{d,j} S_{d,j} + I \leq \frac{W}{R_{v,req}} \left( \frac{E_b}{N_0} \right)_{v,req} \left( \text{SIR}_v \right)^{-1}_v S_v
\]  

(10)

Where

\[
N_v, N_{d,j}, N_{d,j-1}, \ldots, N_{d,1} \text{ are number of users.}
\]

We can reduce equation (10) to

\[
\alpha_v \left( \frac{N_v}{(\text{SIR})^{-1}_v} \right) + \sum_{j=1}^{N_d} \frac{N_{d,j}}{(\text{SIR})^{-1}_j + \alpha_{d,j}} \leq 1 - z
\]  

(11)

Where

\[
z = \frac{I}{S_v (\text{SIR})^{-1}_v + \alpha_v} = \frac{I}{S_{d,j} (\text{SIR})^{-1}_{d,j} + \alpha_{d,j}}
\]  

(12)

For a single cell system, the other cell interference has no effect on the capacity, and the term \( z \) of (11) is set to zero. Therefore, (11) is simplified to the following equation for a single cell case:

\[
\gamma \cdot N_v + \sum_{j=1}^{N_d} \gamma_{d,j} N_{d,j} \leq 1 - z
\]  

(13)

where
The equation (13) specifies a capacity plane in the \( N \) dimensional space.

All points \( N_{v}, N_{d_{1}}, N_{d_{2}}, \ldots, N_{d_{N}} \) under the hyper plane represent possible numbers of supportable users in voice and data user groups in a sector. In (13) the total resource amount of the system, the resource amount used by one voice user, and the resource amount used by one data user in the group \( j \) correspond to \( 1, \gamma' \) and \( \gamma_{d_{j}} \), respectively. Equation (13) also means that the resources used by users should not exceed total system resource.

III. USERS BEHAVIOR MODEL

Here we evaluate a Markov model with a storage queue which is suitable for traffic calculations of data traffic (Internet and VoIP traffics). Data traffic can be conveyed either through circuit switch systems or packet switch systems.

Circuit switch systems have usually constant bit rates, while packet switch systems may have variable bit rates. So far there are some Erlang tables that are only pertinent to voice traffic in circuit switch systems.

Now to handle the data traffic we consider a queuing model which contains \( m \) servers. That system includes \( K \) customers (including the customers in service). Besides, we assume that the population is infinite \((M/M/m/K)\). We can use this model for data services because we assume they are delay-tolerant and when all \( m \) channels are busy, upon reception of a new call attempt, it will be inserted into the queue before it is lost.

The birth and death coefficients in this situation are as follow (see also Fig. 1).

\[
\lambda_{n} = \begin{cases} 
\frac{\lambda}{m} & n < K - 1 \\
0 & n \geq K 
\end{cases} 
\]

and

\[
\mu_{n} = \begin{cases} 
n\mu & n \leq m \\
m\mu & m < n \leq K \\
0 & K < n 
\end{cases} 
\]

in which \( n \) is the number of the subscribers in the queue who their attempts have been accepted.

We assume \( P_{n} \) is the probability of being in the state \( n \) (or there exist \( n \) subscribers in the system). On the other hand it indicates the percentage of the time that the system contains \( n \) subscribers and \[13\]

\[
P_{n} = C_{n}P_{0} 
\]

in which

\[
C_{n} = \begin{cases} 
\left( \frac{\lambda}{m} \right)^{n} \frac{1}{n!} & n < m \\
\frac{1}{m!} \sum_{j=0}^{m} \left( \frac{\lambda}{m} \right)^{j} \frac{1}{j!} & m \leq n \leq K \\
0 & K < n 
\end{cases} 
\]

and

\[
P_{0} = \frac{1}{1 + \sum_{n=1}^{K} \left( \frac{\lambda}{m} \right)^{n} \frac{1}{n!}} 
\]

Now if we assume that there is not any queue in the system so that when all servers are busy the call attempts are lost, the above formula will change to Erlang B formula as

\[
P_{n} = \frac{\lambda^{n}}{n!} 
\]

in which \( P_{n} \) describes the fraction of time that all servers are busy. Calls have a (memory-less) exponential duration distribution with \( \lambda \), the arrival rate of new calls (birth rate) per unit time and \( h=1/\mu \), Busy Hour Traffic (BHT), is the time duration (in the above unit time) of a call during the busiest period of the operation (we have assumed a call terminates with "rate" \( \mu \)).

We can show (20) by \( B = (N, \lambda/\mu) \) and write

\[
B(N, A) = \frac{N!}{\sum_{k=0}^{N} \frac{A^{k}}{k!}} 
\]

where \( B \) is probability of blocking, \( N \) is the number of trunks (channels) and \( A = \lambda h \) total amount of the offered traffic in Erlang.

Because of the similarity in the traffic statistical models of the incoming and outgoing voice and data traffic users, we can use (17) for computing the new suggested Erlang D tables for the three kinds of Telnet, www, Email traffics [5]. Note that

\[
\gamma' = \frac{\alpha_{v}}{(SIR)_{v}(v, q)} + \alpha_{v}, \quad \gamma_{d_{j}} = \frac{\alpha_{d_{j}}}{(SIR)_{d_{j}(d, q)}} + \alpha_{d_{j}} 
\]
the Erlang B tables result from a delay non-tolerant Markov model and the Erlang D tables result from a delay tolerant Markov model.

Another important quality of service factor in the mixed traffic systems is delay. According to [14] an end-to-end delay must not exceed 100ms and 200ms for voice and video services respectively.

IV. CALCULATIONS

We also consider a flat fading channel with perfect power control in the reverse link and parameters

\[ W = 5 \text{Mbps}, \quad \alpha_c = 0.375, N_c = 100, R_d = 384 \text{Kbps} \] and

\[ E_b/N_0=5\text{dB} \] for all voice users. We can find data activity factor, \( \alpha_d \), in Table I. We consider a multi-cell environment with 2dB other cell interference and four simultaneous different kinds of traffic users WWW, Email, Telnet and voice. Data users have 384kbps and voice users have 9.6kbps rates. Besides we assume \( E_b/N_0v=5\text{dB}, E_b/N_0d=12\text{dB} \) and the number of voice users=250. The numbers of the calculated traffic users in some arbitrary times are listed in Table II.

<table>
<thead>
<tr>
<th>TABLE I. ACTIVITY FACTORS FOR DATA RATE 384Kbps [15]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ON duration(s)</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Telnet</td>
</tr>
<tr>
<td>www</td>
</tr>
<tr>
<td>E-mail</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE II. NUMBER OF USERS FOR 4 MIXED TRAFFIC each with 384Kbps R ate, ( E_b/N_0v=5\text{dB}, E_b/N_0d=12\text{dB} ) AND NO. OF VOICE USERS=250</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of WWW users</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

As an example, for blocking 2% and voice or circuit switch data traffic without any storage (Erlang B table) with 50.6 Erlangs we need 61 circuits (trunks) [10].

We see the denominator of (19) in the case \( m \leq n < K \) is larger than the case \( n < m \) which has resulted in less blocking when there is a queue in the system. We also see that if there is a queue in the system, new tables can be extracted from (17) with queue length \( K \) as a parameter.

In the state \( n=K \) there are \( n \) users in the system. Thus the blocking probability is \( P_K = C_K P_0 \) in which

\[
P_K = \frac{A^K}{m! m^K} \frac{1}{A^K} \sum_{i=0}^{K} \frac{A^i}{i!} \frac{1}{m^K m^K} \]

and if the offered traffic is \( A = \frac{\lambda}{\mu} \), we have

\[
P_K = \frac{A^K}{m! m^K} \frac{1}{A^K} \sum_{i=0}^{K} \frac{A^i}{i!} \frac{1}{m^K m^K} \] (23)

It is obvious that (23) is less than (21). We calculate Erlang B from (21) and new Erlang D tables from (23) and Tables II & III. \( K \) is a parameters and always \( m < K \). (21) and (23) are plotted in Figs. 2 & 3 respectively. As it is shown for an amount of the traffic and an equal number of channels, the blocking probability for the case \( K=0 \) is less than the case \( K>0 \).

In addition, with an optimum radio resource management for 50.6 Erlangs Telnet traffic, we can convey at most 50.6/0.0019 = 19765 users each with the speed of 384kbps (see Table III).
Table III has listed the blocking probability versus the traffic volume for the individual traffic users. \(K\) is a parameter and \(m=1\).

As we know maximum carried traffic of \(m\) channels is \(m\) Erlangs. Thus each curve in Figs. 2 & 3 are valid up to the amount that the carried traffic is valid and some parts of the Figs. 2& 3 are not valid.

**TABLE III. COMPARISON OF THE ERLANG B & D TABLES RESPECTIVE TO 384kpbs WWW TRAFFIC, Eb/N0=5dB, Eb/N0d=12dB AND NO. OF VOICE USERS=100 (M=1)**

<table>
<thead>
<tr>
<th>Traffic-ww users</th>
<th>Erlang B</th>
<th>Erlang D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blocking</td>
<td>Blocking</td>
</tr>
<tr>
<td>0.01-4</td>
<td>0.0099</td>
<td>9.9e-5</td>
</tr>
<tr>
<td>0.05-19</td>
<td>0.0476</td>
<td>0.0024</td>
</tr>
<tr>
<td>0.07-27</td>
<td>0.0654</td>
<td>0.0046</td>
</tr>
<tr>
<td>0.1-39</td>
<td>0.091</td>
<td>0.009</td>
</tr>
<tr>
<td>0.15-57</td>
<td>0.13</td>
<td>0.115</td>
</tr>
<tr>
<td>0.2-78</td>
<td>0.167</td>
<td>0.0323</td>
</tr>
<tr>
<td>0.3-117</td>
<td>0.321</td>
<td>0.0647</td>
</tr>
<tr>
<td>0.4-156</td>
<td>0.286</td>
<td>0.102</td>
</tr>
<tr>
<td>0.5-195</td>
<td>0.333</td>
<td>0.143</td>
</tr>
</tbody>
</table>

\(K=0\) \(K=2\) \(K=3\)

It is shown from Tables III that the larger the \(K\) the smaller the blocking probability.

First column of Tables III is in the form xx-yy. The left xx is the offered traffic. The right yy is the number of the WWW traffic users each with 384kbps data rates. For example for \(m=1\), \(K=2\) and 0.4 Erlang traffic, traffic of 156 www users can be conveyed with 10.2% blocking. We can consider \(m\) either as the wireless channels or wired channels between the switching centers.

**V. IP TRAFFIC PLANNING**

We should consider different parameters for QoS traffic evaluation in circuit and packet switch networks, i.e. packet and circuit switch QoS evaluation should be done differently. The following table denotes some of these parameters.

**TABLE IV. PARAMETERS OF THE NETWORK EVALUATION**

<table>
<thead>
<tr>
<th>Term</th>
<th>Circuit Switched parameters</th>
<th>Packet Switched parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td>Offered traffic in Erlang</td>
<td>Offered amount of data rate</td>
</tr>
<tr>
<td>QoS parameters</td>
<td>Blocking probability, Frame loss</td>
<td>Throughput, Delay, Packet loss, Packet drop</td>
</tr>
<tr>
<td>Tools</td>
<td>Simple formula or table</td>
<td>Offered traffic table *</td>
</tr>
</tbody>
</table>

* It is a function of Eb/No, data rate, source activity factors, other cell interference and queue length.

As it is seen, blocking probability has not been one the packet switching QoS parameters, but according to our method and calculation the activity factors of different Internet traffic types, it also entered the packet switch QoS parameters category. Thus the traffic planning method will change to as shown in the Fig.4.

**Figure 4. Network traffic planning procedure**

We consider a cell with the following parameters \(Eb/N0v=5dB\), \(Eb/N0d=12dB\), Internet traffic rate=384 kbps, voice traffic rate=9.6kbps, data activity factors as in Table 1 and voice activity factor=0.375. Besides, we assume there are 57 WWW users, 56 Email users, 12 Telnet users (row 7 in Table 2) and 250 voice users which all are active. Total rate of the voice traffic is 250*9.6=2400kbps. Dividing it by 384kpbs we find 6.25. If we multiply it by 0.375 we find 2.4 which the number of 384kbps channels for conveying traffic of 250 voice users. For data traffic users we find 57*0.00256+56*0.0033 +12*0.0019= 0.35 Erlang. Thus the total number of the channels are 2.4+0.35 =2.75Erlangs (m=3).

To compute the maximum blocking rate we must compute the Whole of the Traffic WoT as \(WoT=57*0.00256+56*0.0033 +12*0.0019=0.35\) Erlang.

One of the above circuits must support a rate of 384kbps. Besides an efficient radio resource management module can handle all of the above traffics. Now if the number of the channels is \(m=4\), from (7) we see B=0.958 which means no call is ongoing (assuming \(m=95\) we find B=0.0722 which is suitable), but if we consider a queuing system with \(m=4\) and \(K=6\) we find B=0.0031 which indicates a good improvement in blocking. However, this system is not realizable because the system delay is too long.

**VI. CONCLUSION**

We calculated a formula for calculating number of the circuits for a pure data system with a queue and introduced the new Erlang D tables which is affected by the number of Internet users with the specific Eb/No, data rates, source activity factor and other cells interferences in a multi-user system. We also saw the dependency of the traffic tables or
the number of users carried by the circuit to the above parameters in wireless systems. At the end we defined different QoS parameters and procedures for each of the circuit and packet switch systems and in a case study, using that criteria we used the above tables for calculating the total number of channels and whole of the traffic.

REFERENCES


