Performance Analysis of GSM/GPRS System with Channel Impairment

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Abstract

In a wireless environment, the impairment of communication channels can affect significantly the performance of broadband wireless system. This paper presents an analytical model on the performance of a GSM/GPRS system with channel impairment. The model incorporates the interfering effects causing by the bit error rate of affected channels and the possibility of corrupted channels. Our model is based on a Markov-modulated Poisson Process (MMPP) used for traffic integration of voice and data in a GPRS system. With the effect of interference embedded in the model, the result would provide valuable realistic information for the design and implementation of such systems.

1. Introduction

General Packet Radio Service (GPRS) is a new bearer service based on GSM architecture which provides mobile subscribers with performance guaranteed packet data services over GSM radio channels. With its packet-switched characteristic, GPRS enables mobile service providers to make more efficient use of the resources while providing mixed service capability for both real-time and non real-time application. The issues concerning the allocation of available bandwidth for particular types of service (i.e., voice or data) are still being investigated extensively. There is enormous ongoing research that investigates the integration of mixed service especially voice and data. In [1], an analytical Markov model was investigated to provide the number of packet data channel that should be allocated for GPRS under a given amount of traffic, for guaranteed quality of service. In [2], various algorithms for GPRS radio resource allocation are proposed. This research work includes consideration for dynamic GPRS packet acceptance rate. In [3], Mahdavi et al. have investigated a GPRS Markov-based model that performs complete sharing scheduling of real and non real-time services. Also, a novel expeditious computational algorithm for a GPRS model is proposed in their work. In [4], a Hybrid radio resource allocation (HRRA) was investigated. This research work shows the performance of GPRS system, when dedicated number of GSM voice calls are used for GPRS data packet transfer.

It is well-known that, radio channels are subject to channel impairments. Impairments in wireless environment could be noise, signal fading, jamming, multipath, etc. Consequently, the radio channel assigned to the GPRS services is not always clean and, sometimes, even the efficient coding schemes used to combat interference can fail. The system would require retransmission in response to corrupted packets, resulting in degradation of the performance. The state of each GPRS radio channel can be described as multiple state channels based on channel quality. With this impact on the state of radio channel, channel impairment has major influences on the overall performance of GPRS systems. A number of studies on performance of GPRS system have been done as described above but none so far has dealt with the effect of impairment of the radio channels. This paper presents the analytical model based on Markov Modulated Poisson Process (MMPP) which incorporates the effect of channel impairment (In the rest of this paper, “interference” and “channel impairment” will be used interchangeably) In the next section, background on GPRS is presented. Section 3 present the analytical model based on MMPP and apply the effect of channel impairment into the model. In Section 4, we present several possible scenarios and the numerical results of our analysis. The conclusion is presented in section 5.

2. General Packet Radio Service

GPRS (General Packet Radio Service) is a new packet-based data service over the existing GSM network, which promises to provide higher rate and instant connection of data services. With a theoretical maximum speed of up to 171.2 kbits/sec in contrast to 9.6 kbits/sec of SMS over GSM network, GPRS is the ideal solution for mobile operators to provide wireless Internet services such as Web browsing, ftp, multimedia and so on. In terms of user benefits, GPRS provides fast data services on mobile terminals and may as well be a less costly mobile data service compared to SMS and Circuit Switched Data. GPRS offers an “always connected” service where no dial-up modem connection is needed; the user can access data service without connection phase delay. Since GPRS offers

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much higher rate than the conventional mobile systems, new and better wireless data application has been created, transforming mobile phones into a multimedia wireless terminal.

In terms of network benefits, GPRS employs packet switching where the information is split into small packets. Each packet will be reassembled at the destination. With this technique, GPRS uses spectrum more efficiently since the radio resourced are used only when users are actually sending or receiving data. The radio resource is allocated as requested (no dedicated radio resources). GPRS uses IP protocol to provide data services as in the Internet (best-effort service in nature) therefore the well-known Internet applications will be available on the GPRS network as well. Also, The GPRS network can be viewed as a sub-network of the Internet with GPRS capable mobile phones being viewed as mobile hosts.

GPRS Network Architecture of and Performance

The GPRS architecture is based on the GSM network with additional dedicated nodes, which are used to provide GPRS services. In the GSM network, a mobile station (MS) communicates with based station subsystem (BSS) for radio resource and control signaling. The BSS is connected to the mobile switching center (MSC). The MSC communicates with the visitor location register (VLR) and home location register (HLR) to keep track of the location of mobile users. In Fig 1, the GSM network is modified to support GPRS service by introducing two GPRS support nodes: a serving GPRS support node (SGSN) and a gateway GPRS support node (GGSN).

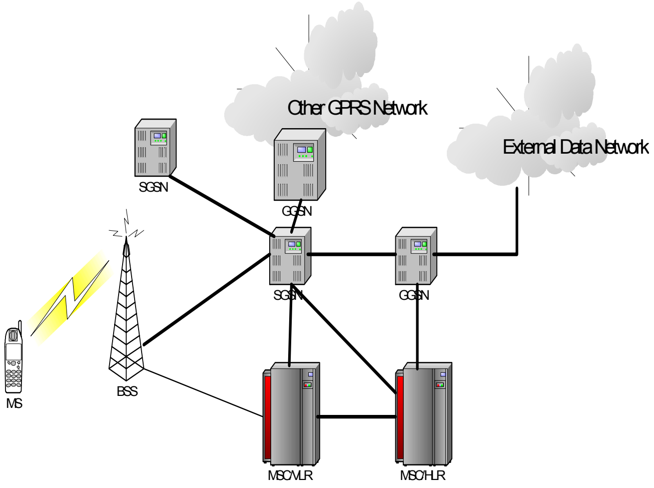

Fig 1. GPRS architecture

The serving GPRS Support Node (SGSN) delivers packets to MSs within the service area. It detects new GPRS mobile station and queries home location register (HLR) to get user profile data and keeps track of location of MSs. Gateway GPRS Support Node (GGSN) interfaces with external IP networks (internet or other GPRS networks). It provides external interfaces and standard router services (QoS, DHCP, DNS and IP routing) and also maintains routing information for SGSNs.

Even though GPRS can reach up to a theoretical speed of 171.2 kbps, in reality, the achievable transmission rate is a lot lower than expected (approximately 50kbps). The performance of a GPRS system is seriously suffered from its best-effort architecture, causing reduction in transmission rate when the system experiences high volume of aggregated traffic. Another important reason for degradation in transmission rate is interference. Similar to other wireless system, interference is a major problem: either packet lost or they are corrupted at the receiver. A channel coding scheme can alleviate the problem. However, it cannot correct all the errors occurred from severe interference. Retransmission is often required in this case which will bring down the successful transmission rate. Therefore, in order to understand the performance of GPRS system realistically, incorporation of interference is required in the performance model.

3. Analytical model

3.1. Model Description and Parameters.

The model is applied for a pair of spectrum assigned in an integrated GSM/GPRS network. The arriving voice and data calls are modeled according to two mutually independent Poisson processes. Both of them are scheduled to share the radio resource. We assume that the channel is slotted with some fixed slot duration and the number of slots is N. All N channels can be shared by both voice and data calls. However, voice calls have the right of priority and preemption over data calls. The data calls, which cannot immediately be transmitted, are queued at the source. In our model, we consider the downlink of the base station as a FIFO where there is no contention mechanism and data calls are handled when there are available channels.

Voice calls can be modeled as M/M/N/N regulated by the erlang-B formula, where N is the number of service channels. The arrival of voice calls is Poisson process with an arrival rate of λ_v and a service rate is μ_v. Again, the packets from voice traffic have higher priority over data packets, if there is no available channel, the channel that is in use by data users will be reallocated for voice packets and will be released right after the voice calls is terminated. For the data calls, each call request is processed and if it is accepted, the session for that data called is initiated. The data requested by the data users comes in bursts. We assume that our single cell has a certain number of data users, M, and each of them has a data session. The interarrival time is exponential distributed with rate λ_d and burst length $1/\mu_d$.

Since arrival packets from both voice and data users are sharing the same resources, they are correlated. We can model the employed traffic by using a Markov-modulated Poisson Process (MMPP). The MMPP has been extensively employed for modeling traffic processes with time-varying arrival rate. Its main advantage is the ability to capture some of the important correlations between the interarrival times. In our model, we assume that if there are *i* data users in the queue, *M-i* users are in reading mode. Therefore the set of arrival rate of data users is

$$\lambda_i = (M-i)\lambda_d \tag{1}$$

where i = 0,1,2,……,M

The set of service rate of data users is (refer to [3])

$$\mu_j = (N-j)\mu_d \tag{2}$$

where j = 0,1,2,……,N = number of available channels

3.2 Channel impairment model

As time goes by, a service channel could be degraded by the effect of interference. We can assume that any of the N channels can be either free of interference or corrupted with interference. We can describe it in terms of good or bad states. Each state of MMPP can go back and forth between a good state and a bad state where the bad state has relatively slower service rate. The state diagram of MMPP that is subject to interference is shown in Fig.2. The transition rate between the good and the bad state is governed by parameters α and β. The probability of channels being in the bad state is

$$P_{bad} = \frac{\alpha}{\alpha+\beta} \tag{3}$$

The service rate of the good and bad channel for the data users can be derived as in follows.

$$\mu_g = \mu_d = \frac{1}{l}\frac{C}{E(R_g)} \tag{4}$$

$$\mu_b = \mu_{db} = \frac{1}{l}\frac{C}{E(R_b)} \tag{5}$$

where $E(R_g)$ and $E(R_b)$ are the average number of times that a packet is transmitted (and retransmitted) in a good, or a bad channel, respectively. *l* is the maximum number of packet transmission. In a good channel, it is typical that $E(R_g)$ is slightly larger than 1; but in a bad channel, we expect that $E(R_b) >> E(R_g)$, thus, $\mu_b << \mu_g$. As described in [5], $E(R_g)$ and $E(R_b)$ are readily determined in terms of the BER's in the good and bad channel. Therefore, the set μ_j for good and bad channels are $\mu_j = (N-j)\mu_d$ and $\mu_{jb} = (N-j)\mu_{db}$, respectively.

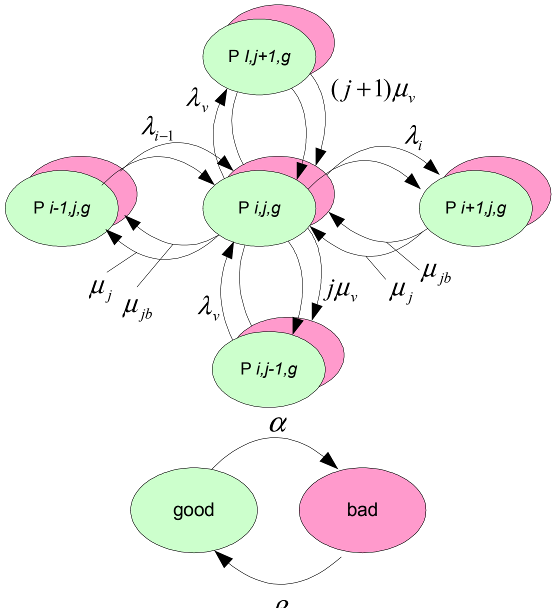

Fig.2 State diagram of MMPP with interference

We can now set up the state balance equations as follows.

For i=0 and j=0

$$(\lambda_v + \lambda_0 + \alpha)P_{0,0,g} = \mu_v P_{0,1,g} + \mu_0 P_{1,0,g} + \beta P_{0,0,b}$$

$$(\lambda_v + \lambda_0 + \beta)P_{0,0,b} = \mu_v P_{0,1,b} + \mu_{0b} P_{1,0,b} + \alpha P_{0,0,g}$$

For i=0 and j=j

$$(\lambda_v + \lambda_0 + j\mu_v + \alpha)P_{0,j,g} = (j+1)\mu_v P_{0,j+1,g} + \mu_0 P_{1,j,g} + \lambda_v P_{0,j-1,g} + \beta P_{0,j,b}$$

$$(\lambda_v + \lambda_0 + j\mu_v + \beta)P_{0,j,b} = (j+1)\mu_v P_{0,j+1,b} + \mu_{0b} P_{1,j,b} + \lambda_v P_{0,j-1,b} + \alpha P_{0,j,g}$$

For i=0 and j=N

$$(\lambda_0 + N\mu_v + \alpha)P_{0,N,g} = \lambda_v P_{0,N-1,g} + \beta P_{0,N,b}$$

$$(\lambda_0 + N\mu_v + \beta)P_{0,N,b} = \lambda_v P_{0,N-1,b} + \alpha P_{0,N,g}$$

For i=i and j=0

$$(\lambda_v + \lambda_i + \mu_0 + \alpha)P_{i,0,g} = \mu_v P_{i,1,g} + \mu_0 P_{i+1,0,g} + \lambda_0 P_{i-1,0,g} + \beta P_{i,0,b}$$

$$(\lambda_v + \lambda_i + \mu_{0b} + \beta)P_{i,0,b} = \mu_v P_{i,1,b} + \mu_{0b} P_{i+1,0,b} + \lambda_0 P_{i-1,0,b} + \alpha P_{i,0,g}$$

For i=i and j=j

$$\begin{aligned}(\lambda_v + \lambda_i + j\mu_v + \mu_j + \alpha)P_{i,j,g} = {} & (j+1)\mu_v P_{i,j+1,g} + \mu_j P_{i+1,j,g} + \lambda_v P_{i,j-1,g} \\ & + \lambda_{i-1} P_{i-1,j,g} + \beta P_{i,j,b}\end{aligned}$$

$$\begin{aligned}(\lambda_v + \lambda_i + j\mu_v + \mu_{jb} + \beta)P_{i,j,b} = {} & (j+1)\mu_v P_{i,j+1,b} + \mu_{jb} P_{i+1,j,b} + \lambda_v P_{i,j-1,b} \\ & + \lambda_{i-1} P_{i-1,j,b} + \alpha P_{i,j,g}\end{aligned}$$

For i=i and j=N

$$(\lambda_i + N\mu_v + \alpha)P_{i,N,g} = \lambda_v P_{i,N-1,g} + \lambda_{i-1} P_{i-1,N,g} + \beta P_{i,N,b}$$

$$(\lambda_i + N\mu_v + \beta)P_{i,N,b} = \lambda_v P_{i,N-1,b} + \lambda_{i-1} P_{i-1,N,b} + \alpha P_{i,N,g}$$

For i=M and j=0

$$(\lambda_v+\mu_0+\alpha)P_{M,0,g}=\mu_v P_{M,1,g}+\lambda_{M-1}P_{M-1,0,g}+\beta P_{M,0,b}$$

$$(\lambda_v+\mu_{0b}+\beta)P_{M,0,b}=\mu_v P_{M,1,b}+\lambda_{M-1}P_{M-1,0,b}+\alpha P_{M,0,g}$$

For i=M and j=j

$$(\lambda_v+j\mu_v+\mu_j+\alpha)P_{M,j,g}=(j+1)\mu_v P_{M,j+1,g}+\lambda_v P_{M,j-1,g}+\lambda_{M-1}P_{M-1,j,g}+\beta P_{M,j,b}$$

$$(\lambda_v+j\mu_v+\mu_{jb}+\beta)P_{M,j,b}=(j+1)\mu_v P_{M,j+1,b}+\lambda_v P_{M,j-1,b}+\lambda_{M-1}P_{M-1,j,b}+\alpha P_{M,j,g}$$

For i=M and j=N

$$(N\mu_v+\alpha)P_{M,N,g}=\lambda_v P_{M,N-1,g}+\lambda_{M-1}P_{M-1,N,g}+\beta P_{M,N,b}$$

$$(N\mu_v+\beta)P_{M,N,b}=\lambda_v P_{M,N-1,b}+\lambda_{M-1}P_{M-1,N,b}+\alpha P_{M,N,g}$$

From the state balance equations, we can obtain the steady-state probability of MMPP. Let $\underline{P}=[\underline{P}_0,\underline{P}_1,\ldots\underline{P}_i,\ldots\underline{P}_M]$ denote the state probability vector, where $\underline{P}_i=[P_{i,o,g},P_{i,0,b},P_{i,1,g},P_{i,1,b},\ldots\ldots P_{i,N,g},P_{i,N,b}]$. Then, $\underline{P}$ can be found as the solution of the state equation $\underline{P}\cdot K=0$, along with the normalization condition $\underline{P}\cdot E=1$ where K is the infinitesimal generating matrix of the MMPP, which is constructed from the state balance equation derived above and $\underline{E}$ is the usual column vector of 1's.

By given the state probability vector, $\underline{P}$, we can calculate the average queue length and waiting time using the Little's formula as follow.

$$\text{Average queue length} = L_{avg}=\sum_{i=1}^{M} i.\underline{P}_i \quad (6)$$

$$\text{Average. waiting time in queue} = \frac{L_{avg}}{\lambda_d(M-L_{avg})} \quad (7)$$

4. Numerical results

We consider a pair of spectrum of GSM/GPRS system. Each pair of spectrum has 8 timeslots per frame. However, only six timeslots (N=6) can be used (two timeslots are reserved for signaling). The voice call holding time is 120 seconds. The arrival rate of voice calls is set in such a way that the probability of blocking is 1%. We assume that the interference would affect significantly on the data transmission. In particular, the service rate of the channels for data users with interference will be decreased since more retransmission is required for the corrupted channel. The service rate of channels with interference can be derived from BER as in [5]. Fig.3 shows the average waiting time in the queue versus number of data users. In this scenario, we have the probability of channels being in the bad state equal to 50% and Channels change state every 30 seconds. The result shows the increment of waiting time in the queue when channels are affected by interference. The level of interference is indicated by the value of BERs. As we can see, with BER=10E-5, the interference is small enough that it does not have significant effect on the performance of the system. However, with larger interference (higher BER), the degradation on the performance increases significantly, as we expected. In the next scenario, Fig 4 shows the average waiting time in the queue for different probabilities of channel being in the bad state (P_{bad}). The BER used for each curve is 10E-3. It can be seen that, as P_{bad} increases to1, the average waiting time in the queue increases causing the performance of the GPRS system to degrade significantly. This is an interesting result since it indicates that there are two parameters that affect corrupted channels by interference: one is the bit error rate of the channels, which the interference could be approximately as a certain value for a particular phenomenon such as scattering rain, sand storm, etc. The second is the possibility of communication channels to be corrupted or probability of channels being in bad state (P_{bad}). P_{bad} can be determined by the geographical information of the affected area e.g., climate, population (city or rural area), etc. This parameter affects the overall performance of the network in relative longer term.

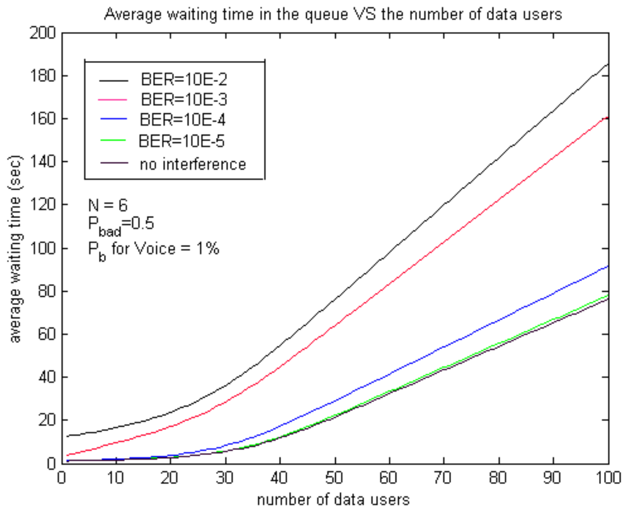

Fig.3. Average waiting time VS number of data users at various values of BER for bad channels. (Channel state changes every 30 seconds in average and probability for channels being in bad state =0.5)

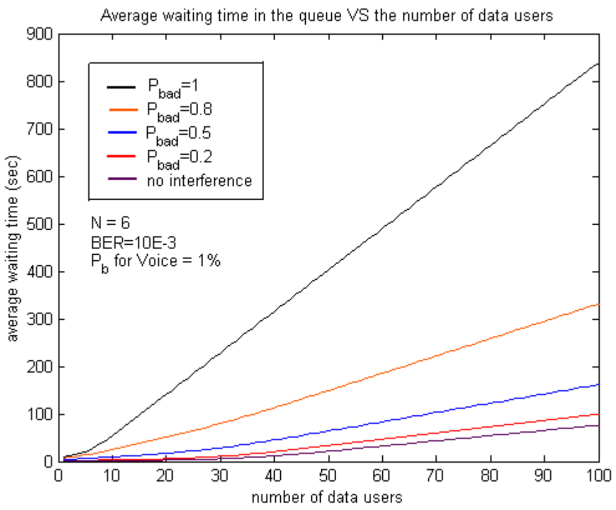

Fig 4. Average waiting time VS the number of data users for different probabilities of being in bad channel (P_{bad})

5. Conclusion

In this paper, we have presented an analytical study regarding a GSM/GPRS system taking channel impairment into consideration. The paper focuses on the interference effect of data transmission in GPRS system that provides mixed service (real and non-real time services). The interference parameters are embedded in our analytical model, which provides a realistic look of a GPRS system implemented in a different environment. Numerical results showed that the proposed model is able to incorporate the effect of interference by taking into account the bit error rate of impaired channel and the possibility of channels being corrupted. This result could be very useful for design and implementation issues of GPRS systems or even third generation wireless systems, in different geographical areas.

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