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Study of Cellular Primary User Frequency Occupancy Statistical Features

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Abstract: Mobile-cellular subscriptions' frequency occupancy behaviors significantly affect how the radio spectrum can be efficiently utilized. This study presents the statistical features of cell load, channel occupancy rate, call duration, call inter-arrival time and channel idle time by analyzing speech traffic signaling messages collected from GSM Abis interface of several base stations of a Chinese city. Innovations of this present study lie in two aspects. First, all the statistics are derived from the signaling messages of Abis interface, so the analysis can be deepened into channel level. Second, the real data about traffic statistics are revealed while not the normalized data. Cell loads fluctuate both in one day's span and in a few minutes. Heterogeneity is observed among one cell's different channels. Call inter-arrival time can be perfectly fitted into an exponential distribution but the parameters vary with the mean load. The 20% of all traffic channel occupancy durations are below 7 sec which causes that the channel duration cannot be fitted as exponential function. It is also shown that the call duration distributions are relatively stable among different time period and different base stations and can be fitted into Birnbaum-Saunders distribution. The revealed primary spectrum occupancy statistical features can be used for spectrum auction, wireless resources management, call model building and other spectrum secondary usage related scenarios.

Key words: Primary occupancy, cognitive radio, cell load, call duration, call inter-arrival time

INTRODUCTION

The Cognitive Radio (CR) has been recognized as a promising technique to significantly improve the spectrum efficiency compared with traditional fixed spectrum allocation. This means the Secondary Users (SUs) can obtain the spectrum from the spectrum market (Caicedo and Weiss, 2011) or just competitively use the spare spectrum with other SUs. For the licensed Primary Users (PUs), if they know when and where and how much the spare spectrum will occur with what kind of probability, it will be helpful for spectrum auction. As for the SUs, the PU spectrum occupancy statistical features will help efficiently sense and select the most suitable channels. Also it will help to better simulate the PU spectrum occupancy behaviours. Hence, it is necessary to understand the PU behaviours in the particular spectrum bands where the Dynamic Spectrum Access (DSA) techniques are demanded to deploy. Note that in cellular networks, the access to spectrum has been planned into channels which may be Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA) or else. So, the SUs have to adapt to the specific wireless access methods, from sensing to using the channels, to avoid impairing PUs. For instance, in GSM, a 200 kHz bandwidth radio frequency channel is divided into eight time slots. Each full-rate traffic channel (TCH) occupies one time slot. Not just the spectrum is channelized but also the great variation of cellular traffic both in time and space bring challenges in deploying DSA techniques.

Recently, a number of measurement studies have been carried out to capture the spectrum occupancy characteristics in a wide frequency bands. In (Taher *et al*., 2011), year by year first-order statistics about the spectrum occupancy across multiple bands are given, especially focusing on TV band. The authors describe the results from a series of 6 months observations of spectrum occupancy in the range 300 MHz-4.9 GHz made at a single location (Harrold *et al*., 2011). Van de Beek *et al*. (2011) study the availability of TV white spaces in Europe, also study the influence of

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different modelling assumptions on their results, especially focusing on the impact of the choice of propagation model. In (Mwangoka *et al*., 2011), the authors introduce an approach for efficient sharing of TV white spaces in European context. Ghosh *et al*. (2010) introduce a framework for statistical wireless spectrum occupancy modelling. In that model, they assume that the call inter-arrival time and call duration obey exponential distribution and use sensing based data to evaluate its performance.

In this study, a GSM Abis interface signaling collection based cellular primary users spectrum occupancy characterization analysis is presented. As the best of our knowledge, no similar study is based on the Abis call signaling collection. The cellular spectrum bands are concerned by the following causes. Cellular networks occupy the most suitable frequency bands for wide areas wireless communication, in which many communication devices have been developed and can be taken into the secondary usages. In addition, for the secondary usage of cellular spectrum, there are some special challenges, such as high usage variation and channelization of spectrum. Also because of the above mentioned reasons, both the PUs and SUs want to utilize the idle channels. Hence the GSM spectrum occupancy characteristics of primary users are worthy of careful study. Some prior studies (Taher *et al*., 2011; Harrold *et al*., 2011; Van de Beek *et al*., 2011; Mwangoka *et al*., 2011; Holland *et al*., 2007; Kamakaris *et al*., 2005) have given some statistics of cellular PU spectrum occupancy. But all the above studies are based on active spectrum sensing. It is well known that energy sensing based study has its inherent drawbacks. For example, it can only inspect a small range of spectrum at any time, so it will inevitably overlook partial PU activities and cannot obtain complete and accurate PU frequency occupancy activities. Guo *et al*. (2007) study the GSM call duration probability distribution using the data recorded in Mobile Switch Center. However the authors just focus on the call duration and the data are just from two selected hours in two successive days. In (Willkomm *et al*., 2008), similar to this study, Willkomm *et al*. (2008) have given an extensive study on the call load, call duration, call inter-arrival time and the load spatial variations. The authors obtained the data from the call log files of one U.S. CDMA operator. However this study still has many differences compared with literature (Willkomm *et al*., 2008). Firstly, the data used in this study are collected from GSM Abis interface in a Chinese city, which has high population density. Note that GSM is TDMA, so the spectrum usage pattern is different with CDMA. Secondly, the analysis has been deepened into traffic channel level which is the basic unit that SUs can use. Thirdly, some actual statistical data are revealed instead of normalized data.

DATA SET DESCRIPTION

The data set used in this study was extracted from GSM Abis interface signaling messages of several BTSs of a China's GSM operator. The GSM Abis interface is the interface between base tranceiver station and Base Station Controller (BSC). The Tektronix K1297, a signaling message collector and analyzer, was used to collect the call signaling of some BTSs in Huangshi city, Hubei, China, lasting from several hours to 25 h. From the recorded signaling, the interested Channel Activation and RF Channel Release messages are extracted to obtain the time stamp and channel number info for each speech call during the signaling collection time. The resolution of all the time used in this study is 1 msec. Figure 1 shows the signaling message collection process.

In this study the signaling collection of any cell does not last more than one day. Some studies have given the traffic load figures in more than one day (Harrold *et al*., 2011), (Willkomm *et al*., 2008). It is showed that in most of the cases the load of a cell has a cycle of one day. So the statistical data can be assumed to be stationary among different work days.

STATISTICAL FEATURES STUDY

In this section, three typical BTSs are taken to analyze their statistical features of traffic load, call duration and call inter-arrival time.

Load of BTSs: From the data set, three typical BTSs' traffic load figures are plotted. They show the fluctuating occupied speech traffic channel number of BTSs. All these three BTSs are located in high population density areas and each BTS is deployed with three co-located cells. These three BTSs are named as BTS1, BTS2 and BTS3, who's load is showed in Fig. 2 from top to bottom. These three BTSs are configured with 24, 24 and 12 GSM radio frequency channels in GSM 900 MHz band, respectively. Note that each frequency channel can carry at most 8 full-rate traffic channels. So, these three BTSs can at most provide 192, 192 and 96 traffic channels. Below, if not specifically pointed out, a channel means a full-rate speech traffic channel. Just as many studies have revealed that the load varies greatly. In the rush hours, the load climbs its peak and in the midnight, it usually becomes zero. Even in the busy hours, the fluctuation may exceed 30% of the peak load.

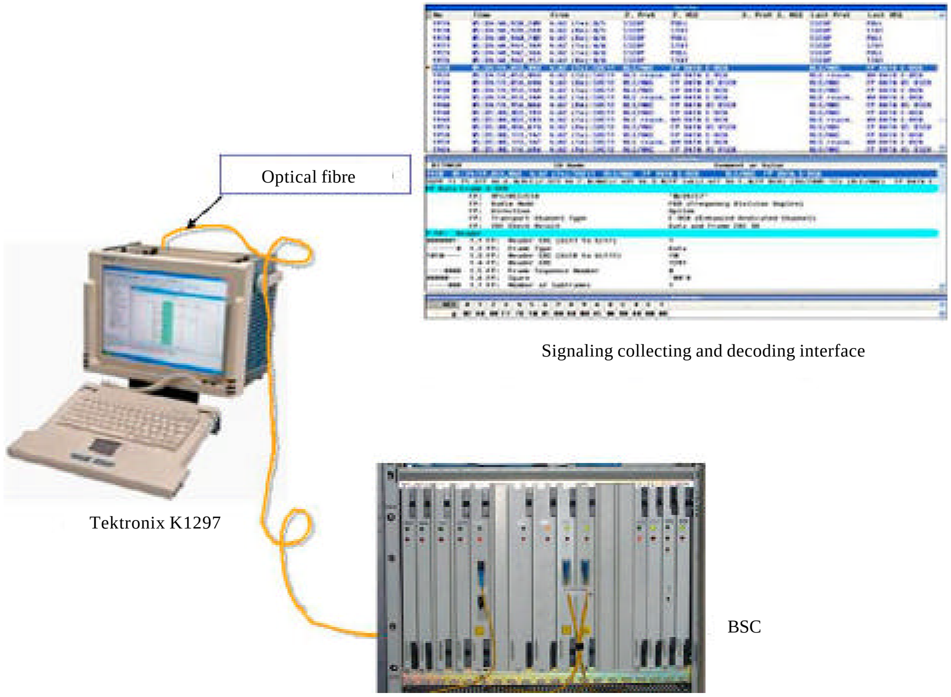

Fig. 1: Signaling collection diagram

The load figure manifests that each BTS's load begins to decrease until zero in the midnight. The exact hours when the traffic load begins the night time decrease may be different among different BTSs at different places. For example, Fig. 2 shows the time when these three BTSs' load begin to decrease is around 7, 9:30 and 10 pm, respectively. From 2 to 6 am, all the BTSs maintain very low load. It is nature that the load change reflects the human work and rest routine.

The load distribution among different channels in one cell is also studied. The traffic occupancy rate of each channel of these three BTSs is showed in Fig.3. The occupancy rate from one day's call logs is obtained. Each BTS has three co-located cells and has 192, 192 and 96 channels, respectively. Each cell, belonging to the same BTS, has the same number of channels. The completely idle channels showed in Fig. 3 mean that these channels are used as common control channels whose channel numbers never appear in the channel activation messages. From Fig. 3, it is observed that the mean channel occupancy rates are different among different cells and also among different traffic channels belonging to the same cell. To show it intuitively, the channel occupancy during the first 4000s of signal collection of channel 4 and channel 7 of BTS1 is plotted. The results are showed in Fig. 4 (Top and Middle). The sorted channel occupancy rates of BTS1 are showed in Fig. 4

Table 1: Call duration percentage statistics

Date	6-7s	≤7s	≤60s	≤100s	100-600s	>600s
BTS1-Parts						
1	11.34	22.62	86.32	94.33	5.52	0.15
2	16.22	28.90	84.80	91.46	7.64	0.90
3	12.96	24.45	87.88	95.21	4.61	0.18
BTS3	15.89	27.31	88.13	94.32	5.31	0.37

(Bottom). By tracing the channel activation and release sequence, we observe that the idle channels are pushed into a stack. When a new call comes, a channel is allocated by popping one from the idle channel stack. When a call ends, the released channel is pushed into the idle channel stack. So the channel, which is on the bottom of the stack at the beginning, will have more idle time than others in a certain period of time.

Call duration: The call duration of each call of the three BTSs is given in Fig. 5. It indicates that the extremely long calls, say over 1 h, most happen in late night. But the total number of very long calls is very small.

To know if the call duration probability distribution may change greatly by time or space like the traffic load, BTS1 and BTS3 are further investigated. For BTS1, one day's time is divided into three parts. Part-1 is from 9 am to 8 pm, part-2 is from 8 pm to 4 am and part-3 is from 4 am to 9 am. From Table 1, it is found that the three parts' call durations have very similar probability

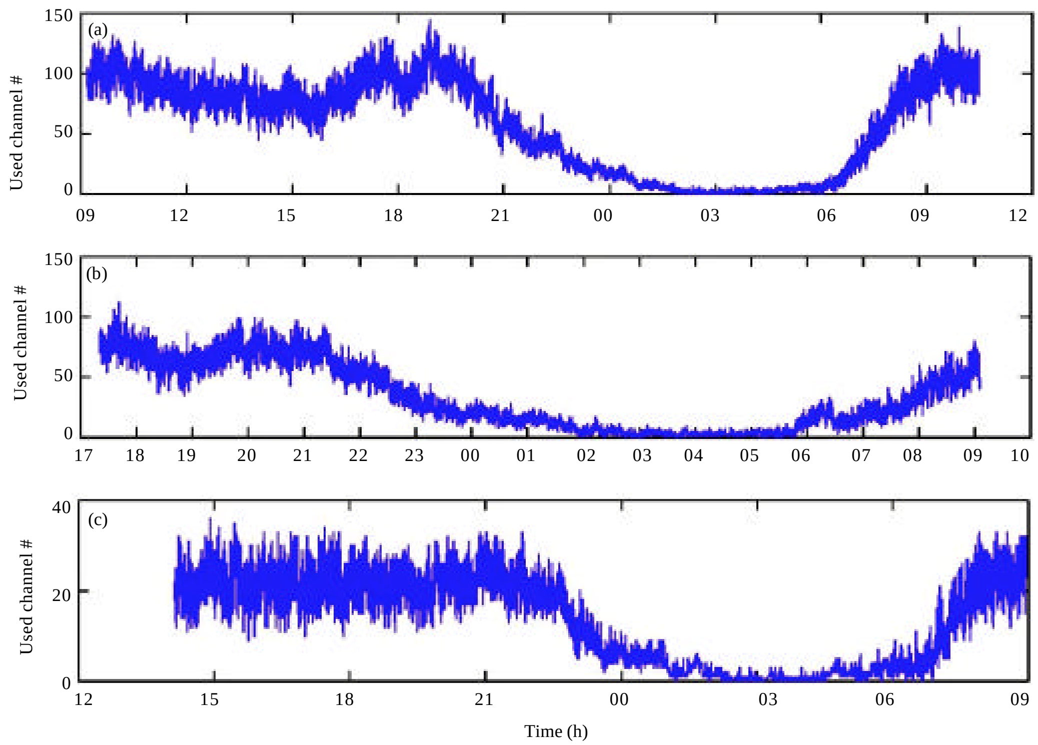

Fig. 2(a-c): One day’s load of, (a) BTS1, (b) BTS2 and (c) BTS3

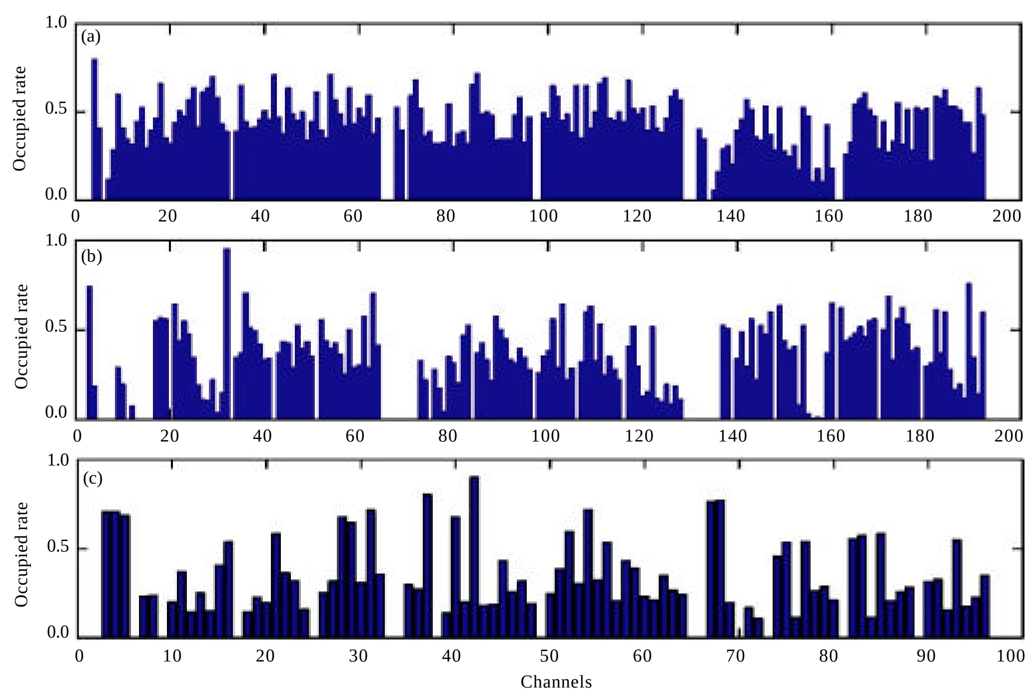

Fig. 3(a-c): Occupancy rates of all the channels of, (a) BTS1, (b) BTS2 and (c) BTS3

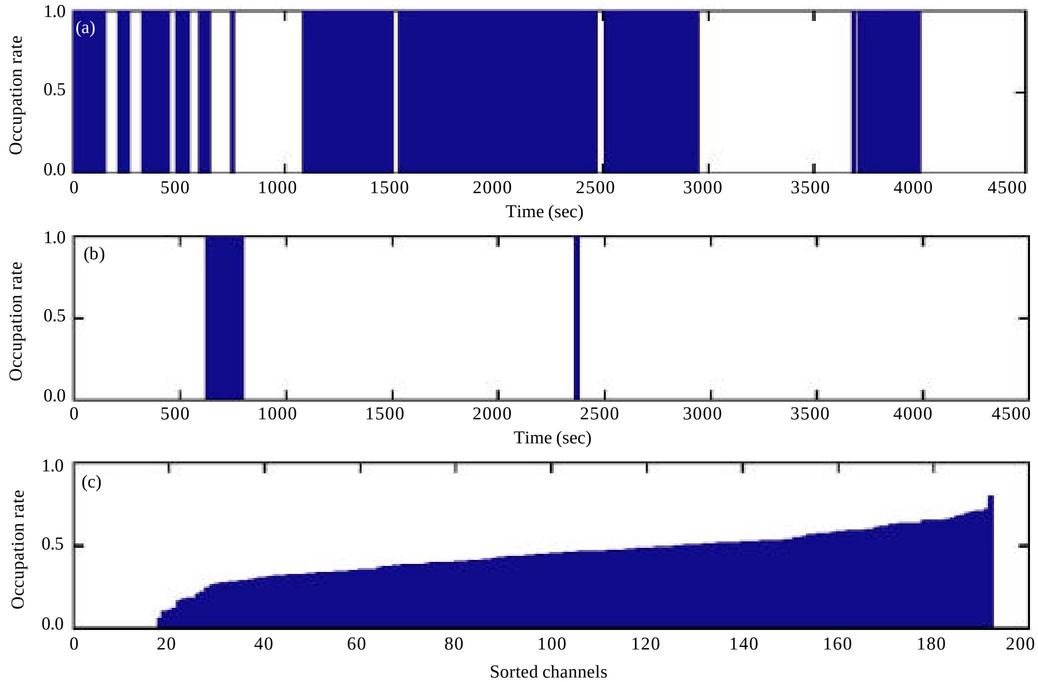

Fig. 4(a-c): (a) Channel occupancy of channel 4 of BTS1, (b) Channel occupancy of channel 7 of BTS1 and (c) Sorted channel occupancy rate of BTS1

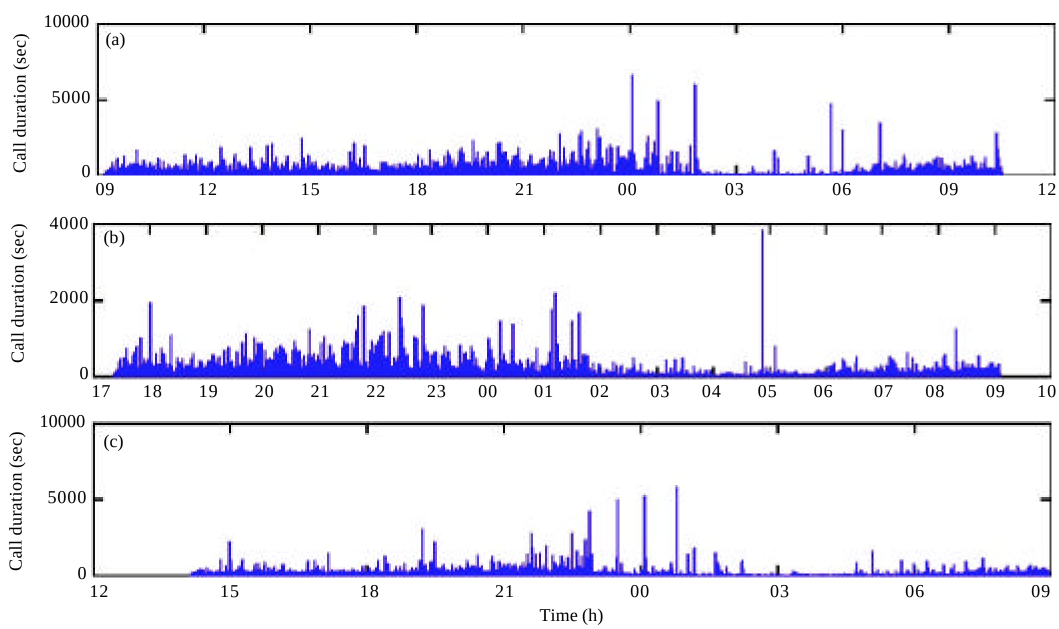

Fig. 5(a-c): Call duration of, (a) BTS1, (b) BTS2 and (c) BTS3

distributions. Only the long call percentage in part-2 is significantly higher than other parts'. But the absolute percentage is still very small. It shows that the probability distribution is stationary in different time of one day. The

BTS2' call duration probability distribution is also given in Table 1. It has no significant differences compared with BTS1's. It is notable that over 20% call duration is shorter than 7 sec. This phenomenon can be explained as the results of handoffs, call losses and quickly ended calls. The call lost means the traffic channel has been established but the call has not been answered. The quickly ended calls usually happen at the beginning of a speech connection when the speech quality is bad and the mobile users may hang up and dial again. The ping-pong effect can cause frequent handoffs between neighbor cells which causes a lot of channel activation and release in short time. The call statistics of one BSC in Huangshi, Hubei, China, which includes 193 cells, during one day in 2009 from 8 am to 8 pm, indicates that 42.32% of the channel allocation requests are from handoffs. This statistics proves that the short time channel occupancies are mainly caused by handoffs.

The MATLAB distribution fitting tool is used and it is found that the Birnbaum-Saunders distribution is suitable to fit the call duration data of BTS1. The result is plotted in Fig. 6. The mean value is 33.1 sec of all 149,738 calls. The Birnbaum-Saunders distribution parameters are beta 19.4 and gamma 1.19 with estimate stander error as 0.050 and 0.0022, respectively. Because of their similarity, only the probability distribution density of BTS1 is presented in Fig. 6 for lack of space.

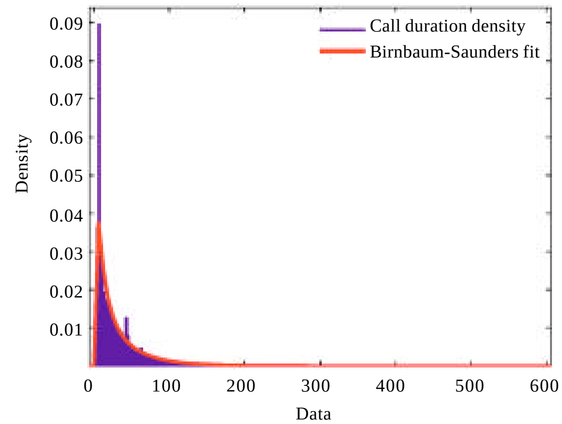

Fig. 6: Call duration probability distribution and its Birnbaum-saunders distribution fitting

Call inter-arrival time: The call inter-arrival time of a BTS is tightly relative to the mean load. In general, when the load is high the inter-arrival time is short and vice versa. In order to avoid the influence of load change, the day hours' data are taken to count the call inter-arrival time probability distribution. The part-1 data of BTS1 (during part-1 time period, the mean load maintains at a high level) is taken and the distribution is plotted as showed in Fig. 7. It shows that the call inter-arrival time distribution can be well fitted as an exponential function. The function is f (x) = a*exp (b*x), a = 2.618, b = -2.626. The mean of the call inter-arrival time is 0.3862 sec which is very close to 1/a, the expectation of this exponential distribution function.

The busy hours' call inter-arrival time distribution of BTS2 and BTS3 is also plotted. It shows that all these three BTSs' call inter-arrival time probability distributions can be well fitted into exponential functions. The result figures are not presented here for the limitation of space. Note that even for the same BTS, the fitted exponential distribution parameters should be different when the mean load changes greatly, e.g., day hours and midnight hours.

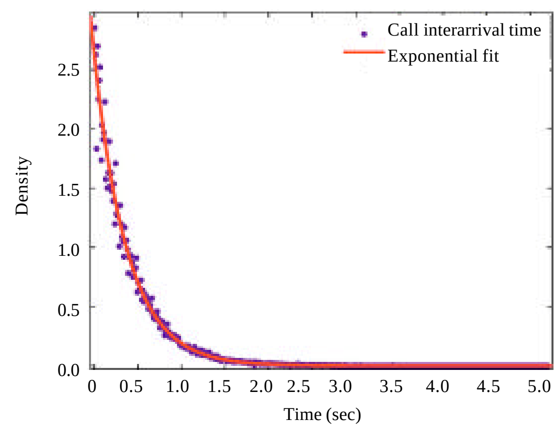

Fig. 7: Call inter-arrival time probability distribution of the busy hours of BTS1

For the calculated time periods of these three BTSs, the mean occupied channel numbers are 91.269 and 21.9 and the mean call inter-arrival times are 0.3862, 0.4004 and 1.5671 sec.

CONCLUSION

This study presents a statistical feature study of cellular primary user frequency occupancy in GSM frequency bands. The call signaling message records collected from GSM Abis interface of three BTSs over one day are analyzed. Using this data set, the load variances of BTSs and the load distribution among channels in one BTS are investigated. Besides, the probability distributions of call duration, call inter-arrival time, channel idle time are presented. Several results are derived, some of which are summarized below:

- The call arrival-interval time can be well fitted as exponential distribution. The call duration has significant deviations from exponential distribution, for more than 20% of short calls with only several seconds duration. But it can be fitted as Birnbaum-Saunders distribution. It should be noted that the mean call inter-arrival time is highly interrelated with the mean load, while the call duration does not. So when the mean load changes, e.g., during day hours and during midnight hours, the call inter-arrival time distribution parameter changes correspondingly
- The channel allocation strategy can significantly change the load distribution among those channels of one cell. From the observed data, we find that the channel occupancy rates change among channels. Note that one cell is an independent channel management entity and one channel is the basic spectrum usage unit by secondary users. So the individual channel occupancy statistical features deserve more investigation
- It is suggested that this study provides some useful fundamental knowledge of GSM primary user spectrum occupancy features. Based on better understanding of PUs speech traffic statistical features, wireless resource management, DSA channel sharing schemes, spectrum auction strategies and etc., can be further optimized to meet the real call statistics

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