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Generalized Dynamic Channel Allocation for TD-SCDMA Systems

Tae-Young Min[*], Byeong C. Kim[**], Joung C. Kim[**], and Chung G. Kang[*]
E-mail: {ehozo, ccgkang}@korea.ac.kr
[*] Department of Electrical Engineering, Korea University
[**] Mobile Device & Access Network R&D Center, SK Telecom

Abstract – **This paper proposes a generalized version of a dynamic channel allocation (DCA) algorithm for a TD-SCDMA system, which is adaptive to aspects of the steadily varying communication environment such as user distribution, channel allocation of adjacent cells, channel condition, and so on. It aims to fully utilize the physical resource available in the time-division duplexing (TDD) system subject to the various types of inter-cell and intra-cell interference. The simulation results have shown that the proposed DCA scheme improves the outage performance while reducing the average system interference, allowing for full utilization of the physical resource over a wide range of acceptable outage performance.**

I. INTRODUCTION

TD-SCDMA is a 3G wireless mobile communication system that has evolved as a time division duplexing (TDD) version of the 3GPP standard. It adopts a code division multiple access (CDMA) technology specialized for TDD with the unique feature of uplink synchronization, which is to mitigate intra-cell interference among the users assigned in the same time slot. Furthermore, joint detection and smart antennas are adopted as another means of mitigating intra-cell interference as well as inter-cell interference.

Furthermore, dynamic channel allocation (DCA) is one of the most critical technologies that govern the overall capacity and service quality in the cellular network. In systems that support variable uplink and downlink resource partitioning, such as TD-SCDMA, DCA can play an essential role in managing the various types of inter-cell interference, including the cross time slot interference that is a unique aspect in TDD systems since one time slot can be used by two adjacent cells, e.g., as an uplink in one cell and as a downlink in the other cell. Unlike the existing DCA algorithm that works well with a uniform user distribution, we propose a generalized version of the dynamic channel allocation (DCA) scheme that is specialized to the varying user distribution. It is designed to be robust to aspects of the steadily varying communication environment such as user distribution, channel allocation of adjacent cells, channel condition, and so on.

This paper is organized as follows. Section II presents an overview of the TD-SCDMA system while illustrating the concept of DCA with respect to the specific types of inter-cell interference. Section III introduces the proposed DCA algorithm. Its performance is evaluated using simulations and it is compared with the existing DCA algorithms in Section IV. Finally, concluding remarks are given in Section V.

II. DYNAMIC RESOURCE ALLOCATION: OVERVIEW

A. *System Overview*

The TD-SCDMA system has a multi-code and multi-time slot structure derived from one or more frequency channels of 1.6MHz bandwidth with a fixed chip rate of 1.28Mcps. As in all other 3GPP standards, it adopts a radio frame of 10ms. Each radio frame is divided into two 5ms subframes, each of which consists of 7 time slots (TS's), designated as TS0 through TS6 (see Fig. 1). TS0 is usually used for broadcast channels while TS1 is always used for uplink communication. All other time slots are divided into uplink and downlink time slots with respect to a switching point, e.g., 3 TS's for the uplink and 3 TS's for the downlink as illustrated in Fig. 1.

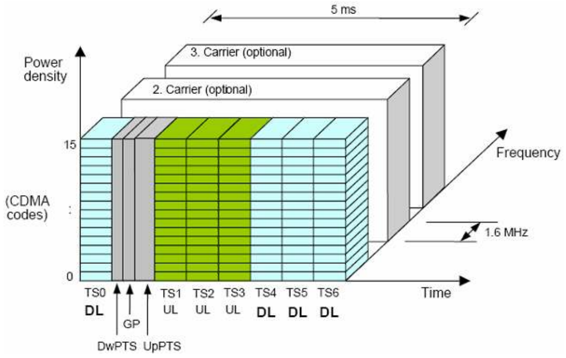


Fig. 1. Radio Resource for TD-SCDMA

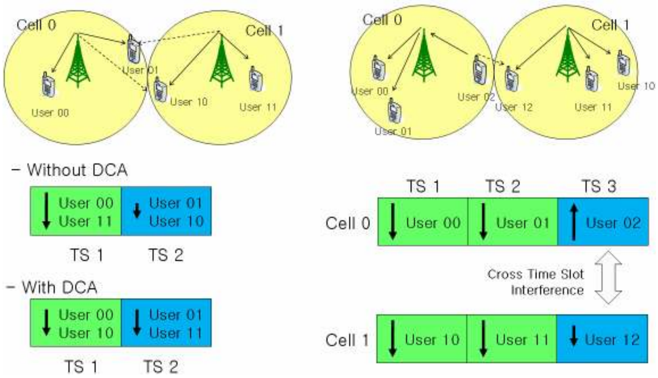
In each time slot, spreading codes are derived from an orthogonal variable spreading factor (OVSF) code tree. The spreading factor for the downlink is fixed to 16 while that for the uplink is given by 1,2,4,8, or 16. Note that 16 orthogonal codes are available from the OVSF code tree for the downlink with a spreading factor of 16. A basic resource allocation unit is defined as a radio unit (RU), which corresponds to one spreading code with a spreading factor of 16.

Assuming that the downlink-to-uplink ratio is 1:1, i.e., 3 TS's in each direction, the total radio resource physically available in the downlink is 48 RU's (= 3 TS's/subframe*16 spreading codes/TS*1 RU/spreading code). The required number of RU's varies with the date rate. For example, voice service at a data rate of 12.2kbps requires 2 RU's for each call. The operational objective in the TD-SCDMA system is to make all of these physical resources fully immune to inter-cell and intra-cell interference. In particular, joint detection will be useful for mitigating the interference among the users allocated in the same time slot. Depending on their location, inter-cell interference can be a critical problem between two users in adjacent cells who are assigned in the same time slot. Smart antennas with directional beamforming capabilities can be another means of reducing inter-cell interference with spatial isolation.

In the following subsection, we illustrate various types of inter-cell interference and investigate how it can be mitigated while fully exploiting the physical resources and preserving the quality of service.

B. *Illustrating Examples for Inter-cell Interference*

There are two different types of inter-cell interference problems, namely, the cell edge near-far problem and the cross time slot problem. These problems are mainly attributed to specific locations of mobile users in adjacent cells. As shown in Fig. 2(a), consider a downlink user *j* in a cell *i*, denoted by U_{ij}. When TS1 is shared by U_{00} and U_{11} while TS2 is shared by U_{01} and U_{10} in the adjacent cells, the interference measured in each slot is different. As U_{01} and U_{10} are closely located at their own cell edges, each BS assigns more power to the user in the cell edge, incurring more inter-cell interference to each other in the same TS.



(a) Cell edge near-far problem (b) Cross time slot problem

Fig. 2. Inter-cell Interference Problems: Illustration

Note that a downward or upward arrow in each TS indicates a level of the signal-to-interference and noise ratio (SINR) for the downlink or uplink, respectively. The dynamic channel allocation (DCA) algorithm intends to select more appropriate users in each TS as a means of reducing mutual interference. For example, a proper application of DCA may select U_{00} and U_{10} in TS1, and U_{01} and U_{11} in TS2, since one user close to BS transmits at the lower power, causing less interference to the other in the edge of the adjacent cell as illustrated in Fig. 2(a). This particular advantage of DCA will be more effective if directional beamforming is applied [4]. In other words, there is a much better chance of selecting a set of users that would be causing less interference among them, due to spatial isolation as well as near-far power control.

In the TDD system, a particular time slot with different directions in the adjacent cells is referred to as a cross time slot (CTS). As illustrated in Fig. 2(b), for example, TS3 is a CTS in which U_{02} and U_{12} are assigned for the uplink and downlink in cell 0 and cell 1, respectively. Herein, a mobile U_{12} in the downlink would suffer from interference caused by a near-by mobile U_{02}, which transmits at much higher power to combat the near-far interference in the uplink. This is a so-called cross time slot problem. In this example, we note that this particular problem can be alleviated if CTS is allocated to U_{11} rather than to U_{12} in cell 1. This is one of the design aspects to consider in the DCA algorithm.

C. *Existing DCA Algorithms for the TD-SCDMA System*

A straightforward approach is to select a time slot for each cell in a random manner, which is referred to as a random channel allocation (RCA) scheme [3][5]. In general, the RCA scheme merely resorts to the interference averaging effect rather than providing any means of interference control. The least interference channel allocation (LICA) algorithm is one particular approach to control interference [1]. The main idea of LICA is to serve an incoming user with the time slot that has the smallest interference. It improves the system performance only when the number of users is small. In this approach, however, the users that arrived later suffer from a shortage of clean time slots, especially when the number of users increases. In fact, it behaves similarly to RCA for a large number of users.

In order to further improve the performance of the RCA or LICA algorithms, location-based DCA algorithms have been proposed, e.g., the region-based or path loss-based cell partitioning DCA algorithms [2][4][5]. These algorithms divide the cell areas into several regions and then select time slots depending on the region in which the users are located. Dividing each cell into 3 different concentric regions, each region is uniquely assigned with one of three time slots so that the same time slots may be physically separated. In fact, it is obvious that both cell edge near-far problem and CTS interference problem are reasonably handled by not allocating the same time slot to the edge of adjacent cells.

All existing cell-partitioning DCA schemes are based on the assumption that all users are distributed uniformly throughout each cell, which balances the interference from each partitioned region. It performs best only when there are infinitely many users that are distributed uniformly in each partitioned region. In a practical realization, however, its performance would be seriously limited by the non-uniform user distribution.

III. GENERALIZED DCA ALGORITHM

As mentioned in the previous section, the cell-partitioned DCA approach performs well with a uniform user distribution with respect to the given regional boundaries. Due to the fact that the number of users to be served at the same time is not large enough, e.g., 24 voice calls at most in the TD-SCDMA system, its performance might be limited. In this section, we propose a new DCA algorithm that is more robust to the user distribution. As it is adaptive to the user distribution, it can be considered as a generalized version of the DCA algorithm.

A. *Motivation*

When one region is overloaded with respect to others (e.g., due to a non-uniform user distribution in the region-based cell-partitioned DCA scheme), a time slot might have to be borrowed from other region. In the existing DCA schemes, however, the second best time slot in each region is not known and thus, it is not clear which time slot should be borrowed. It would be a more critical issue when the system environment steadily changes, especially due to the system load (i.e., the number of users). Therefore, neither the regional boundary nor a second best time slot can be firmly defined for load balancing, which implies that the DCA algorithm must be able to consider the relative co-channel interference levels for each user with respect to all users in the other cells for the varying system conditions. This particular approach allows for generalization of the existing DCA schemes.

B. *Algorithm*

In the proposed DCA scheme, channel allocation is performed with two key elements: update of available channel set (ACS) and slot scheduling. First, the available channel set is defined as a set of time slots whose channel qualities are good enough to be used for each user. The cardinality of the ACS will be used as a priority metric for each user. In particular, the fewer time slots in the ACS, the higher priority of channel allocation given to the corresponding user. It will be used as a primary criterion.

In the first step of the proposed DCA scheme, the ACS is updated for each user. Two different interference thresholds, I_{th_add} and I_{th_del}, are used to add a time slot to the ACS or delete it from the ACS, respectively. Let ACS_n denote a set of available channels for user *n*. At the beginning, all users have no time slot in their own available channel sets, i.e., $ACS_n = \varnothing$. In order to add a time slot to the ACS, the interference to the time slot should be smaller than I_{th_add} during T_{add}. In the meantime, a time slot with an average interference greater than I_{th_del} is deleted from the ACS. Assume that a set of time slots assigned for the downlink of each cell is given and it is denoted by $TS_{DL,k}$ for cell *k*. In addition to available channel set ACS_n, each user *n* maintains a timer associated with each time slot

$i\in TS_{DL,k}$, denoted by $T_{n,i}$. In each of the ACS update steps, each user *n* measures the interference for each time slot $i\in TS_{DL,k}$ at time *t*, which is denoted by $I_{n,i}(t)$. For each time slot *i* of user *n*, the average interference is computed by the following update equation:

$$\bar{I}_{n,i}(t)=\alpha\bar{I}_{n,i}(t-1)+(1-\alpha)I_{n,i}(t) \tag{1}$$

where α is a weight factor. If $\bar{I}_{n,i}(t) > I_{th\_del}$, time slot *i* is deleted from ACS_n, i.e., $ACS_n \leftarrow ACS_n-\{i\}$, and the timer is reset, i.e., $T_{n,i}=0$. Meanwhile, if time slot *i* is not in the available channel set of user *n*, then it can be added into ACS_n as long as the level of the instantaneous interference stays below a threshold I_{th_add} continuously for T_{add} consecutive subframes. In other words, $ACS_n \leftarrow ACS_n \bigcup \{i\}$ if $I_{n,i}(t)<I_{th\_add}$ for $T_{n,i}>T_{add}$. T_{add} is a parameter to confirm the quality of the time slot. The update process of the available channel set is repeated for all time slots assigned to the downlink for all users. . The ACS update procedure for user *n* in cell *k* at time *t* is summarized by the flow chart in Fig. 3.

In the second step, each user is assigned to the time slots of choice, depending on their group priority determined by the cardinality of its own ACS and TS priority, which is determined by slot scheduling. The group priority is used to differentiate the users with less opportunity of using the good time slots from those with good time slots. Those who have fewer TS's in the ACS must be treated preferentially over the others that have one or more alternative TS's. Let a priority group m, denoted by $G_{k,m}$, be a set of users in cell k with m TS's in the ACS, i.e., $G_{k,m}=\{U_{kn} \,||\, ACS_n|=m\}$, $m=0,1,2,3$. Denoting a group priority associated with user n in cell k by $PG_{k,n}$, it is given by $PG_{k,n}=1/m,\ n\in G_{k,m}$, i.e., a higher group priority is given when there are fewer TS's is in the ACS. In other words, the group priority is given in the order $G_{i0}\succ G_{i1}\succ G_{i2}\succ G_{i3}$.

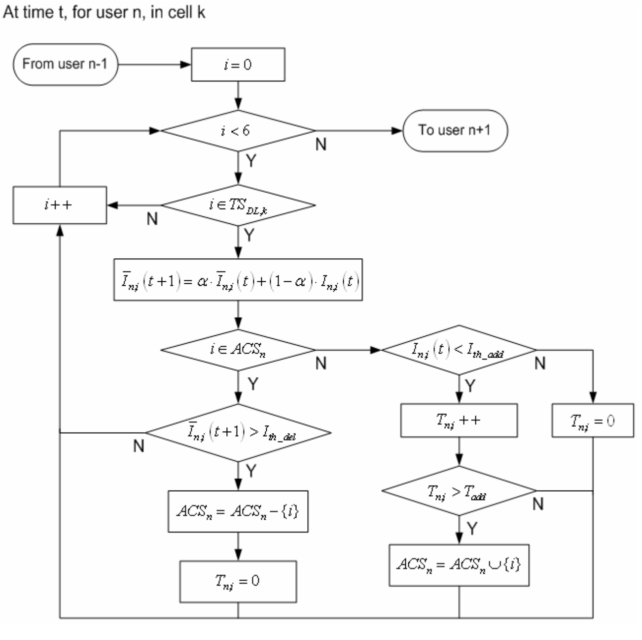


Figure 3. Procedure for Update of the Available Channel Set

As one time slot may be preferred by a multiple number of users within the same priority user group, there must be some means of scheduling the best time slot for each user. This is taken care of by a slot scheduling procedure in the second step of the proposed DCA algorithm. As in LICA, for example, each user may select a time slot with the least interference. In this case, the users who are assigned after the others may suffer by choosing a time slot with more interference. Alternatively, the relative interference levels for each time slot among the different users can be jointly considered so as to maximize the overall performance. Toward this end, we define a relative interference-based priority metric of each time slot for a user as the proportional reciprocal of the average interference among all time slots assigned for the downlink. More specifically, for time slot *i* of user *n* in a priority group *m*, it is given as follows:

$$PR_{n,i}(t)=\frac{-\log\bar{I}_{n,i}(t)}{avg_{j\in TS_{DL,k}}\left[-\log\bar{I}_{n,j}(t)\right]},\quad n\in G_{k,m} \tag{2}$$

where

$$avg_{i\in A}[x_i]=\frac{1}{|A|}\sum_{i=1}^{|A|}x_i \tag{3}$$

A scheduler selects a [user, time slot] pair in the order of the priority score determined by (2). In contrast with (2), the least interference-based priority metric can be defined as follows:

$$PR_{n,i}(t)=-\log\bar{I}_{n,i}(t) \tag{4}$$

The difference between (2) and (4) can be clearly illustrated with a simple example in the following subsection.

C. Slot Scheduling: Illustrative Example

Consider two users in the same priority group, e.g., $G_{k,3}$. Assume that the least interference-based priority scores by (4) are given by Table 1, in which each value represents $-\log\bar{I}_{n,i}(t)$. In this example, User 1 is assigned to TS 1, which has the best score for itself. Then, User 2 has a choice of TS 2 or TS 3. We note that User 2 deserves a better channel, TS 1, as long as User 1 gives up its best channel because it still has a good second best channel, TS2. In other words, a relative interference-based priority metric as in (2) will be useful for handling this rather conflicting situation. Now consider the same example in Table 2 with its entries computed by (2). We first select the highest priory score, which creates the [User 2, TS1] assignment. Then, the next highest priority score is selected for the [User 1, TS 2] assignment. The resulting assignment confirms that the proposed slot scheduling works as expected, i.e., TS 1 is assigned to User 2 rather than User 1, which could not be possible with the least interference-based priority metric (4).

Table 1. Priority Scores for the Interference-based Priority Metric

	User 1	User 2
TS 1	**10**	5
TS 2	9	**2**
TS 3	8	2

Table2. Priority Scores for the Relative Interference-based Priority Metric

	User 1	User 2
TS 1	10/9	**5/3**
TS 2	**9/9**	2/3
TS 3	8/9	2/3

IV. SIMULATION RESULTS

In the current simulation, we consider a TD-SCDMA system deployed with 19 hexagonal cells. One of two different up-down configurations, one with a 2:4 ratio and the other with a 3:3 ratio, are randomly selected by each cell. The simulation is performed for 100 snapshots. All 100 cases realize the different user distributions, different user moves, and different channel conditions. For each snapshot, 8 different simulations are performed by varying the number of users from 6 to 48 in a step of 8 users. Furthermore, a 1000 subframe-long simulation is performed for each [snapshot, user] combination. In each time slot *i* in a subframe, the SINR for each user *n* is measured by the following equation:

$$SINR_{n,i}(t) = \frac{P_{n,i}(t)}{I_{Inter,n,i}(t) + P_N + (1-\alpha_{JD}) \cdot I_{intra,n,i}(t)} \qquad (5)$$

where $P_{n,i}(t)$, $I_{inter,n,i}(t)$, $I_{intra,n,i}(t)$, P_N, and α_{JD} represent received power, inter-cell interference, intra-cell interference, noise, and joint detection elimination factor, respectively. A closed-loop power control is performed to achieve a target SINR at a frequency of 200 Hz with a step size of 1 dB. All simulations are repeated for 3 different DCA algorithms: random allocation, region-based cell-partitioning DCA, and generalized DCA. For the region-based DCA scheme, we follow the algorithm introduced in [4]. Note that the generalized DCA algorithm is only applicable to the downlink, so the region-based DCA is used for the uplink in evaluating the proposed scheme. The simulation parameters are listed in Table 3.

Table 3. Simulation Parameters

Parameter		Value
Cell radius		1 km
Carrier frequency		2.3 GHz
Mobile speed		3 km/h
Maximum transmit power	UE	0.2 W
	Node-B	20 W
Power control	Step size	1 dB
	Frequency	200 Hz
Target SINR ($SINR_{target}$)	Uplink	-7.5 dB
	Downlink	-6.0 dB
Elimination factor (α_{JD})		0.9

We consider two different performance measures: interference and system outage rate. The downlink interference is measured by all users in each frame, and the uplink interference is measured by node-B in each frame. Meanwhile, the outage rate is measured as follows. A user is declared to be suffering from an outage when the corresponding signal to interference and noise ratio (SINR) stays below ($SINR_{target}$ - 2) dB continuously for L frames. The frame outage rate is given by the ratio of the number of frames that are experiencing outage to the total number of frames simulated for each user. Subsequently, the overall system outage rate is defined as the ratio of users whose frame outage is higher than 0.03. As the specific quality of service in the real system is not clearly known, we measure the system outage rate for various values of L. As specified in Table 4, the target outage rates for the downlink and uplink are different.

Fig. 4 shows the average interference measured as a function of the number users in each scheme. It can be seen that the proposed DCA scheme always shows the best performance for the given range of traffic loading. We note that the performance of the region-based DCA scheme is getting close to that of the generalized DCA scheme as the number of users increases. This is because the users are fairly uniformly spread out in each region as the number of users increases.

Figs. 5, 6, and 7 show the outage performance as a function of the number of users for the different outage conditions, i.e., L = 3, 4, 5, respectively. The generalized DCA outperforms the other schemes consistently for different numbers of users and different outage conditions. In fact, the maximum number of users that can be accommodated subject to the specified target system outage rate can be significantly improved with the proposed approach. For example, the system capacity can be improved from 18 users to 37 users at the target outage rate of 0.05. In this case, a maximum of 24 time slots are available, but they are not fully utilized by the existing schemes. However, the proposed scheme allows for full utilization for a target outage rate of 0.05, and it is true over a wide range of target outage rates for the different outage conditions. It is interesting to note that the performance gain of the generalized DCA scheme becomes more significant for certain numbers of users. The region-based cell-partitioning DCA algorithm allocates the resource based on the position of users even when the resources in all of the time slots are available. We intuitively know that there must be a better allocation in this case because there are more opportunities to manage interference by means of allocating resources that are not allocated to adjacent cells. The proposed DCA adaptively figures it out.

Figs. 8 and 9 trace the interference and SINR of a sample user, respectively. The interference levels of the proposed DCA are smaller than the levels for the other algorithms most of the time, as expected. In Fig. 9, however, there is no improvement shown in the SINR. This is simply due to the power control mechanism that attempts to maintain the same target SINR for the different DCA schemes. Based on these observations, we can conclude that a significant power saving effect is achieved, since less interference is present at the same SINR level. In other words, the transmit power has been reduced with the proposed scheme, which subsequently reduces the interference to the adjacent cells.

V. CONCLUSION

Unlike the existing location-based cell-partitioning DCA algorithms that work properly when there is a uniform user distribution, we have proposed a more generalized version of the DCA algorithm that is robust to the steadily varying system conditions, including the user distribution and the channel conditions, in the TD-SCDMA system with directional beamforming capability. It has been demonstrated that system capacity can be significantly increased, possibly to the point of fully utilizing the physical resources over an acceptable range of outage performance. As many design parameters are involved with the current algorithm, more extensive performance studies are required for further optimization. Moreover, the priority grouping and slot scheduling steps in the proposed algorithm can be jointly designed as a unified scheduling step to optimize the overall performance. Finally, it is not clear how much capacity gain can be achieved in a practical system at the acceptable quality of service. These are the remaining issues to be investigated in future research.

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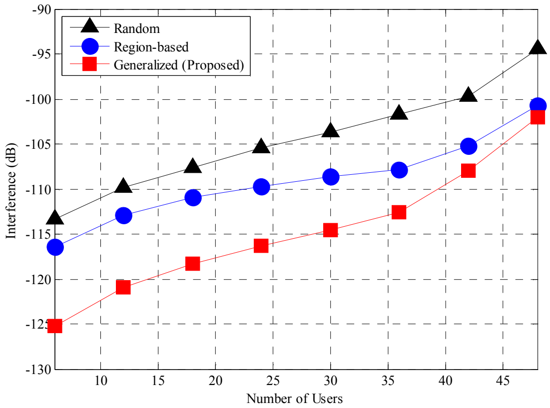

Figure 4. Interference Measurements

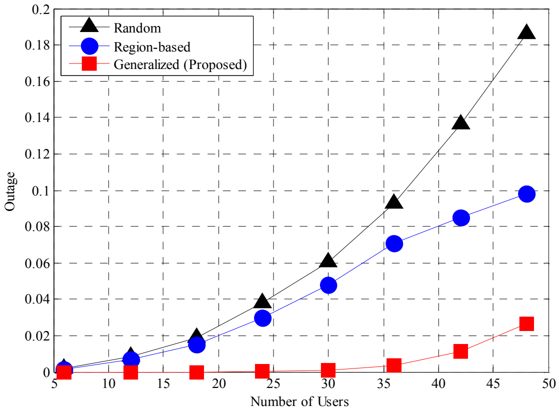

Figure 6. System Outage Rate: L = 4

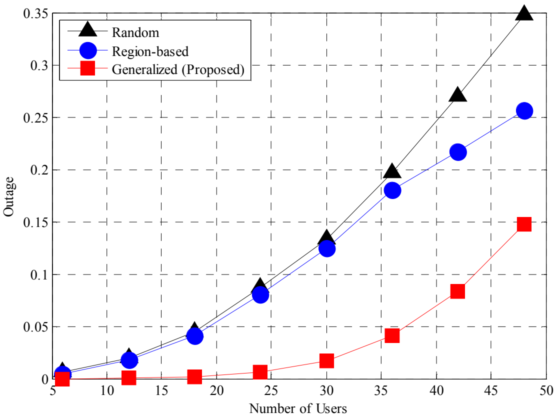

Figure 5. System Outage Rate: L = 3

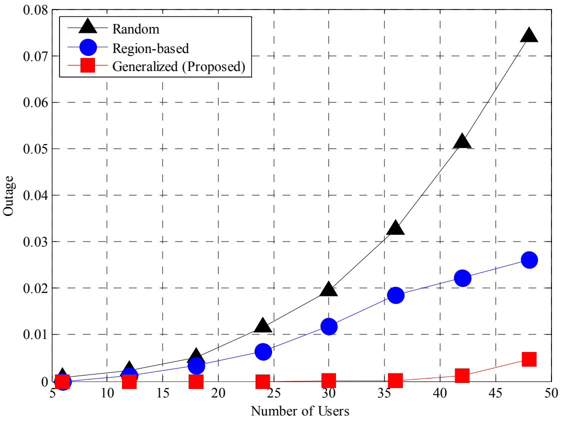

Figure 7. System Outage Rate: L = 5

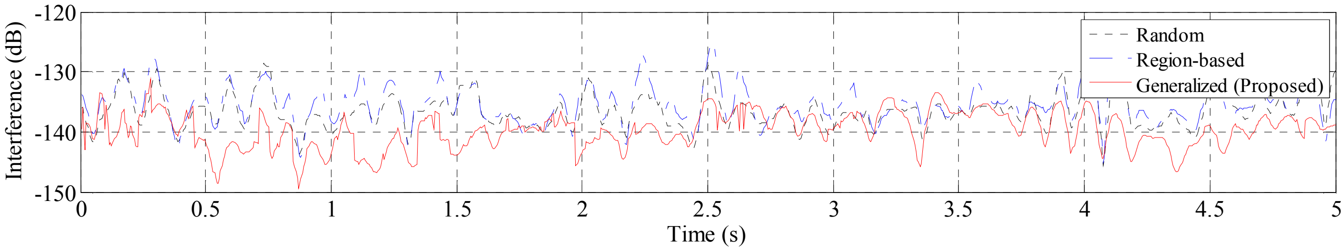

Figure 8. Trace showing the Interference for a Sample User

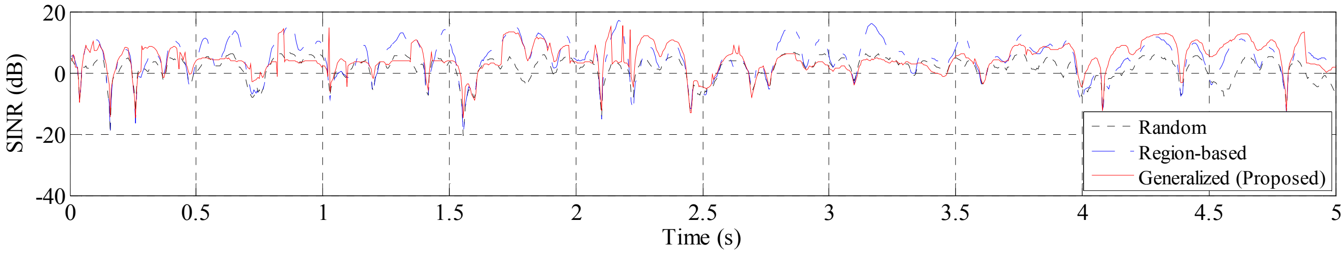

Figure 9. Trace showing the SINR for a Sample User