Simulation study of some PRMA-based protocols with channel reservation for data traffic

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Abstract: Medium access control in mobile network is a challenging issue to tackle with. With the traffic in mobile network becomes more and more bursty, we need packet-switching instead of circuit-switching. Resource allocation in mobile network is also an important issue. For packet-switching-based protocols, packet reservation multiple access (PRMA) is considered as a promising candidate for future mobile networks. In this paper, we first propose a PRMA-based scheme in conjugation with dynamic channel assignment (DCA) in mobile cellular network. Through computer simulation we show that our proposed scheme outperforms the PRMA schemes with fixed channel assignment (FCA). Then, we propose another technique, namely location-based power transmission, to further improve the performance. This scheme can be extended and optimized for other mobile networks, such as mobile ad hoc networks (MANETs).

Keywords: mobile ad hoc networks, medium access control, fixed channel assignment, dynamic channel assignment.

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1 INTRODUCTION

As a key factor in the evolution of wireless communications, mobile ad hoc networks (MANETs) attract attention from many researchers. These networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimization, power control and so on. One challenging issue that we need to tackle with in MANETs is medium access control (MAC). This is due to the following reasons: (1) The terminals in MANETs are moving around and the network topology is changing from time to time; (2) MANETs have no fixed central controller such as an access point (AP) or a base station (BS) which possibly has the global information of the whole network; (3) the MAC protocols for MANETs should be simple to be implemented as mobile terminals has limited processing power and limited battery resource; and (4) real-time traffic such as voice/video transmission often require strict level of quality of service (QoS). Among the existing MAC protocols, IEEE 802.11 (IEEE 802.11 Working Group, 1999) is often used for MANETs. However, it was pointed out that IEEE 802.11 exhibits unfairness when used for multihop mobile networks by (Xu et al, 2001). The traffic in future mobile networks is expected to be more bursty and packet-switching based multiple access protocols are superior to those that are circuit-switching based. Another reason is that the number of subscribers to wireless network is increasing with an incredible speed, which causes the bandwidth sharing to become the bottleneck of wireless communication networks. We need intelligent and powerful multiple access protocols to support the increasing number of subscribers. With the limited bandwidth, packet-switching is needed to support the increasing number of mobile data service subscribers. Packet-switching has no dedicated connection for a user terminal (UT) and can support bursty traffic efficiently.

Packet reservation multiple access (PRMA) technique (Goodman et al, 1989) was proposed to exploit the on-off nature of speech, which consists of a sequence of talkspurt and silence periods, to allow statistically multiplexing of many different speech users. Furthermore, PRMA can also support voice-data-integration (VDI) traffic (Fantacci et al, 1999) as well as multimedia traffic (Elnoubi et al, 2004). PRMA was initially proposed for indoor wireless voice communication. It was shown that PRMA can be extended for the application in MANETs by (Jiang et al, 2002). In the extension, it proposed a method to keep reservation for voice traffic and alert other UTs. However, for data traffic, the proposed scheme is not as efficient as IEEE 802.11. The authors claimed that the deficiency of their proposed scheme can be resolved by introducing a piggyback reservation for data traffic. In this paper, we introduce channel reservation for data traffic to investigate its effect on the performance of PRMA based schemes.

PRMA performs quite well in noise-limited environment. For a wireless network with 20 logical channels, it can support 37 simultaneous voice conversations at the 1% threshold of packet dropping probability from the analytical and simulation results (Goodman et al, 1991 and Nanda et al 1991). However, in an interference-limited system, such as mobile cellular network, the performance of PRMA is limited (Frullone et al, 1996) by the co-channel interference. PRMA can be used in conjunction with two kinds of channel assignment techniques (Lee, 1995), namely, fixed channel assignment (FCA) and dynamic channel assignment (DCA) in mobile cellular network. In this paper, we study the performance of PRMA with FCA and DCA to support Voice-Data-Integration (VDI) traffic in a packet-switching based mobile cellular network. First, we propose a new scheme, PRMA protocol with measurement-base DCA scheme (DPRMA). The proposed DPRMA scheme can employ different measurement-based DCA strategies, e.g., Autonomous Reuse Partitioning (ARP) (Kanai, 1992), Least Interference Channel (LIC) (Cheng et al, 1996) and Most Interfered Channel (Cheng et al, 1996). We use ARP with DPRMA in this paper. We also employ a channel reassignment technique (Li et al, 2005) to improve the performance of schemes significantly. Next, with careful study of the PRMA-based schemes with FCA and DCA, we propose a new technique, namely location based power transmission to reduce the interference level. Finally, the effect of channel reservation for data traffic is investigated. In this study, it is assumed that the feedback packets from a BS are instantaneously available to all UTs (Goodman et al, 1989, Goodman et al 1991 and Nanda et al, 1991), i.e., processing time and propagation delays are negligible.

This paper is organized as follows. Section 2 presents an overview of FCA with PRMA (FPRMA). Section 3 presents the proposed new PRMA-based scheme in conjugation with DCA. Section 4 describes the location based power transmission scheme. In Section 5, we present the channel reassignment technique for voice users and channel reservation for data users employed during the investigation. The simulation model and results are presented in Section 6. Finally, Section 7 concludes the findings of this paper.

2 OVERVIEW OF FPRMA

In FPRMA (Frullone et al, 1996), each cell is assigned $\boldsymbol{C}$ frequency carriers. As shown in Figure 1, each carrier is divided into slots, and organized into frames. Each frame with duration of $\boldsymbol{T_f}$, consists of $\boldsymbol{N}$ times slots with duration $\boldsymbol{T_s}$. For each UT, we will refer to a given slot in a given carrier as a channel, which has the same slot position across repetitive frames. There are maximally $\boldsymbol{C}\times\boldsymbol{N}$ channels in each cell, and they are numbered from 1 to $\boldsymbol{C}\times\boldsymbol{N}$ as shown in Figure 1. The UTs recognize each time slot as ‘A’ (available) or ‘R’ (reserved) channel from a message that is broadcast by a BS at the end of each frame. The frame size is a design parameter, which must satisfy the following condition:

$$N = \left\lfloor \frac{R_c T_f}{R_s T_f + H} \right\rfloor \tag{1}$$

where $\boldsymbol{R_c}$ is the channel transmission rate, $\boldsymbol{R_s}$ is the speech coding rate and $\boldsymbol{H}$ is size of the packet overhead. In this paper, we consider $\boldsymbol{R_c}$ = 720kbps, $\boldsymbol{R_s}$ = 32kbps, $\boldsymbol{H}$ = 64bits and $\boldsymbol{T_f}$ = 16ms (Goodman et al, 1991). Thus the frame size is calculated to be 20. During a talkspurt, speech packets are generated at the frame rate and buffered at the UT for transmission. No speech packet will be generated during a silence period.

The mechanism of FPRMA to support voice traffic is described as follows. A UT $\boldsymbol{A}$ sends the first (oldest) unexpired packet of a talkspurt in one of the available channels, e.g., channel $\boldsymbol{n}$, as part of a contention process. If the packet is received at its BS with an SIR greater than $\boldsymbol{SIR_{min}}$ (minimum acceptable SIR), it is assumed to be successfully decoded and at the end of the slot. The BS informs all UTs within its coverage that now channel $\boldsymbol{n}$ is reserved for UT $\boldsymbol{A}$ until the end of its current talkspurt. When the BS determines that UT $\boldsymbol{A}$’s talkspurt has ended, it broadcasts that the channel $\boldsymbol{n}$ is now available and other

UTs can contend for it in the next frame. If the packet from UT ***A*** is not successfully decoded by the BS, UT ***A*** contends for the next available channel in the next time slot with permission probability, p_v, independent of other UTs. It continues to do so until one of its packets is successfully received. An important design parameter in FPRMA is p_v.

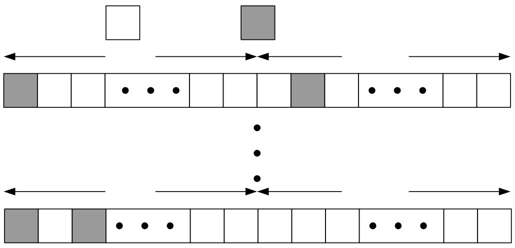


Figure 1 *Frame Structure of FPRMA*

Speech packets can only tolerate limited delays. To reduce the instability and buffer overflow problem, speech packets which have been buffered at the UT longer than a maximum acceptable delay, D_{max}, are dropped and result in the "front end clipping" of the speech at the beginning of the talkspurts. In this paper, D_{max} is set to two-frame time. The voice packet dropping probability is defined as follows.

$$P_d = \frac{\textit{total number of voice packets dropped}}{\textit{total number of voice packets generated}} \tag{2}$$

Furthermore, as we are considering a interference-limited system, such as mobile cellular network, a packet transmitted by a UT in its reserved channel may experience high interference. A talkspurt is said to be *interfered with* if the received SIR at the BS for any one of its packets drops below SIR_{min}. Packets received at the BS with SIR smaller than SIR_{min} are considered lost due to the multiple access interference (MAI). The interference probability is defined as below:

$$P_i = \frac{\textit{total number of voice packets received with } SIR < SIR_{\min}}{\textit{total number of voice packets generated}} \tag{3}$$

PRMA can support VDI traffic. As we know, channel reservation is always done for voice user terminals (VTs). For data user terminals (DTs), we consider two options: one is without channel reservation such that each data packet transmission is contention-based. The other option is with channel reservation such that the remaining packets of a message are transmitted on a reserved channel once a packet is successfully transmitted to the BS in this channel. By default, the channel is not reserved for DTs.

For a DT without channel reservation, it transmits each packet of a message on contention basis. For example, when a message arrives, DT ***B*** will send the first packet in a available channel with permission probability p_d. Notice that VTs transmit their first packet of a voice talkspurt with probability of 1. However, DTs will transmit the first packet with p_d. If the packet is received by the BS with SIR larger than SIR_{min}, DT ***B*** will proceed to transmit the remaining packets of the current message in next available channel in the same way. If the first packet is not successfully received by the BS, DT ***B*** will retransmit it with permission probability p_d in the next available channel again until it is successfully received by the BS. DTs never drop a data packet as messages are loss-sensitive, which means loss of a packet may cause the whole message useless.

3 PROPOSED DPRMA

In this section, we propose a PRMA-based scheme with a measurement-based DCA in conjugation with ARP (DPRMA). In DPRMA, all the channels from all available carriers ($C_{system} \times N$) are numbered in the same way as shown in Figure 1 and they can be used by any BS. C_{system} is the total number of carrier in the system. It is assumed that a BS measures the instantaneous interference power for all its available channels and broadcast them in an interference power list (IPL) to the UTs at the end of each frame. A small number of available channels can be included in the IPL at the expense of some performance degradation. In this study, we assume that all available channels are included in the IPL. Since a UT can estimate the path loss between itself and its BS, it can estimate its instantaneous signal power received at the BS. Hence, the received SIR at the BS for the UT's signal can be estimated with the information provided in the IPL. For example, a VT ***A*** with new talkspurt waits for the end of the current frame and listens to the IPL broadcast by its BS. As shown in Figure 1, it searches for the first available channel, e.g., channel i in slot

$$j = \left\lceil \frac{i-1}{C} \right\rceil + 1 \tag{4}$$

where $\lceil x \rceil$ is the smallest integer that is greater than x, and on carrier

$$k = \left[(i-1) \bmod C\right] + 1 \tag{5}$$

where mod refers to the function modulus, starting from the lowest numbered channel in the IPL for which the estimated SIR is greater than SIR_{setup} (link setup SIR). Then VT ***A*** sends the first packet in channel i on a contention basis. If the BS decodes the packet successfully, it will broadcast an acknowledgement at the end of slot j to inform other UTs that channel i is now reserved for VT ***A*** to transmit the rest of the packets in that talkspurt. When VT ***A*** finishes transmission of the packets generated by its current talkspurt, it will leave channel i empty. Once the BS determines that VT ***A***'s current talkspurt has ended, it broadcasts that channel i is now available. If the first packet of VT ***A*** is not successfully decoded by the BS, it searches for the next available channel starting from the lowest numbered channel in slot $j+1$ and retransmits with permission probability p_v. It continues to do so until one of its packets is successfully decoded by the BS.

A DT searches and accesses a free channel similarly, except two differences: (a) DTs contend to transmit every packet with p_d as they cannot reserve a channel, and (b) p_d for DTs is lower than p_v so that VTs have higher priority to contend a free channel.

4 PROPOSED LOCATION BASED POWER TRANSMISSION SCHEME

For the simplicity of the simulation, the transmission power from all the UTs is usually set to be the same level. However, through simulation, we found that it is more difficult for a UT far away from the BS to achieve a certain level of SIR at the BS than the one near the BS.

From the simulation results shown in later section, it shows that P_i is quite high as compared to P_d and it is due to not enough power for the far UTs. Base on this observation, in this paper, we propose a location based power transmission (LBPT) technique to increase the transmission power for far UTs. Let the cell radius be R. The scheme is described as follows: when a UT i is registered as a BS, if its distance d_i to the BS is smaller than r (a pre-defined threshold), the BS will inform UT i to use transmission power level P_0 dBm; otherwise, the BS will inform UT i to use a higher transmission power level P_1 dBm, which is equal to $P_0+\delta$ dBm. With the use of LBPT, it is assumed that the BS has the distance information. With the aid of global position system (GPS), this information is not difficult to obtain.

In the simulation, the ratio of r/R (where R is the cell radius) and δ are temporally set to 0.5 and 1dB. For the ease of comparison, it is denoted as LBPT(0.5, 1). The scheme is found to be able to reduce the P_i (Frullone et al, 1996) significantly.

5 VOICE CHANNEL REASSIGNMENT AND DATA CHANNEL RESERVATION

In an interference-limited system, under the PRMA protocol, once a talkspurt starts experiencing high interference, the packets in the rest of the talkspurt will most likely be lost leading to very poor performance. To reduce the adverse effect of co-channel interference, we employ the channel reassignment technique introduced in (Li et al, 2005). Channel reassignment (CR) is achieved by dynamically switching an on-going talkspurt on a given logical channel to another channel experiencing less interference. Channel reassignment does not apply to data traffic due to the fact that they are bursty in nature. For a VT A in talkspurt, if the received SIR at its BS for its packet transmitted in a reserved channel n is lower than SIR_{min} for N_{rel} consecutive channels, one of two possible events will occur: (a) the BS will release channel n with probability p_{rel}, if channel n has just been assigned to VT A or (b) otherwise, the BS will just release channel n. After releasing channel n, the BS informs VT A not to transmit in channel n any more and broadcasts that channel n is now available to other UTs at the end of that slot. BS places VT A in a first-in-first-out (FIFO) buffer, and assigns another first available channel to VT A in next frame provided that the estimated SIR in that channel is greater than SIR_{min}. Otherwise, VT A needs to wait in the buffer. In this study, N_{rel} and p_{rel} are set to 2 and 0.5, respectively.

We also investigate the effect of channel reservation for DTs on the performance of PRMA-based protocols. With channel reservation, DTs compete with VTs for the channels. When a message arrives, DT B tries to transmit the first packet of the data message in an available channel, e.g. channel n, in slot s based on contention with p_d. If the first packet of a message is received by DT B's BS with SIR greater than SIR_{min} in both FPRMA and DPRMA, the BS will broadcast that channel n is reserved by DT B at the end of slot s. Then during the following frames, DT B can continuously use channel n to transmit the remaining packets of the current message. Upon finishing transmission of the message, DT B will transmit a null message to inform the BS. Once the BS detects the null message, it will broadcast that channel n is now available. If the first packet is not successfully received by the BS (i.e., there is no positive acknowledgement from the BS at the end of slot s), DT B will retransmit it in next available channel with permission probability p_d. Again, in this study, DTs never drop a packet of a message but retransmit every packet which is not successfully received by the BS. Note that lower p_d should be assigned to DTs compared with the permission probability of VTs, p_v, because voice packets are delay-sensitive and they need higher priority.

6 SIMULATION MODELS AND RESULTS

The simulated area is divided into 27 hexagonal cells with the radius R of 600 meters. A BS is located in the center of each cell and equipped with omni-directional antenna. In order to avoid edge effect, results are collected from the central three cells. The system is considered to be interference limited and thermal noise is neglected. The path loss L in dB between a BS and a UT adopts the following model:

$$L = 10\gamma \log_{10} d + X \quad (6)$$

where the path loss exponent γ =3.5, d is the distance between the BS and the UT and X is a zero-mean Gaussian random variable with a standard deviation of 4 dB. The incoming traffic is randomly generated by 28124 UTs over 27 cells, which are uniformly distributed with 30 m spacing between any two adjacent UTs. UTs are always served by the BS with the highest received signal power. During a call or a message transmission, a UT is assumed to be stationary and the power level is assumed to be constant. No channel fading is considered in this paper.

6.1 Voice and Data Traffic Model

New voice calls arrive according to a Poisson process with arrival rate λ_v calls/second/cell. Voice call durations are exponentially distributed with a mean $1/\mu$ = 120 s. With slow voice activity detector, each call is considered as a combination of talkspurts and silence periods. The durations of talkspurts and silence periods are assumed to be exponentially distributed with mean values of t_1 = 1.0s and t_2 = 1.35s, respectively. Then the offered voice traffic load is given by $\rho = \lambda_v/\mu$ Erlang/cell. Data messages arrive at DTs according to another independent Poisson process with a mean rate of λ_d messages/second/cell. The length of data message is geometrically distributed with a mean length of m = 5 packets. When a new voice call arrives, it is attached to a randomly selected UT, to become a VT. Similarly, when a new data message arrives, it is attached to a randomly selected UT, to become a DT. As we have 28124 UTs, the possibility of that both a voice call and a data message are attached to the same UT is negligible.

6.2 Performance Metrics

For voice traffic, the performance metrics are average voice packet dropping probability, P_d (Goodman et al, 1989, Goodman et al, 1991 and Nanda et al, 1991), average interference probability, P_i (Frullone et al, 1996). For data traffic, the performance metric is average message transfer delay, D_m. It refers to the average time required for a DT to transmit a message completely to its BS. There is a stringent threshold for P_d = 1% in order not to cause any audible distortion to voice calls (Nanda et al, 1991). However, the threshold values of P_i have been used ranging from 1% to 5% (Brand et al, 2002, Frullone et al, 1996, Kondylis et al, 1999). In this study, we consider P_d=1% and P_i=1% as the threshold values. So the voice capacity that can be supported by the system is the capacity at P_d=1% or P_i=1%, whichever is smaller.

6.3 System Parameters

The system parameters considered in this study are shown in Table 1.

Table 1 *System Parameters*

Parameter Name	Value
Frame Time T_f	0.016s
Frame Size N	20
Slot Time T_s	0.0008s
Mean silence gap duration t_2	1.35s
Mean talkspurt duration t_1	1s
Mean call arrival rate per cell λ_v	Variable
Mean call holding time $1/\mu$	120s
Mean message arrival rate per cell λ_d	5
Mean message length m	5
Voice UT permission probability p_v	0.3
Data UT permission probability p_d	0.1
Link Setup SIR SIR_{setup} (for DPRMA only)	15dB
Link Maintenance SIR SIR_{min}	9dB
Release probability p_{rel}	0.5
Number of interfered slots before release N_{rel}	2
Total number of frequency carrier C_{system}	3
Cluster size $N_{cluster}$	3
Maximum delay for a voice packet D_{max}	0.032s

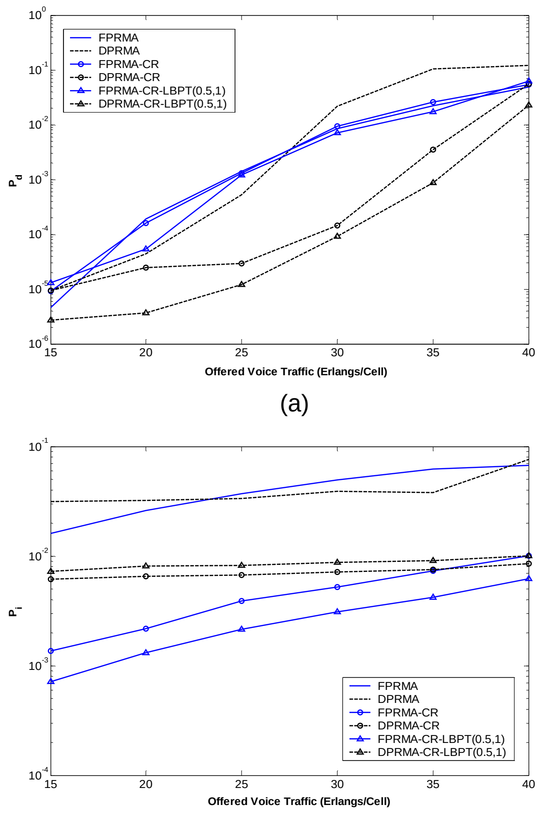
The total number of frequency carriers C_{system} is 3. Each carrier is divided into 20 time slots. Thus, under FCA, with a reuse factor of 3, each cell is allocated with one frequency carrier with a total of 20 channels. Under DCA, 3 frequencies carriers are available in each cell such that there are a total of 60 channels in each cell. Each simulation is run for 14000000 slots (more than 180 minutes). Statistics of the performance metrics from the first 2000000 slots are ignored in order to eliminate the transient effect. For most of the simulation results, the 95% confidence intervals are within ±10% of the average values shown.

6.4 Simulation Results and Analysis

Two types of traffic were considered in the simulation. One is voice-only traffic, in which increasing amount of voice traffic is considered. The other one is VDI traffic, in which a constant amount of data traffic with the increasing amount of voice traffic is considered. We denote FPRMA with CR and DPRMA with CR as FPRMA-CR and DPRMA-CR, respectively. Similarly, FPRMA-CR with LBPT(0.5, 1) and DPRMA-CR with LBPT(0.5, 1) are denoted as FPRMA-CR-LBPT(0.5, 1) and DPRMA-CR-LBPT(0.5, 1), respectively.

6.4.1 Voice-only Traffic

With voice-only traffic, as shown in Figure 2(a), the average voice packet dropping probability P_d increases with increasing amount of offered voice traffic ρ.



(b)

Figure 2 *P_d and P_i with voice-only traffic*

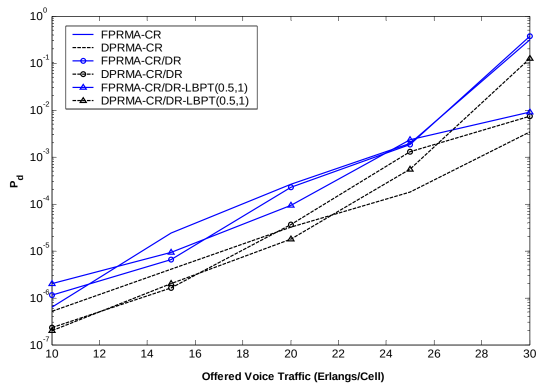
Without CR, compared to FPRMA, DPRMA has lower $\boldsymbol{P_d}$ when $\boldsymbol{\rho}$<25 Erlangs and higher $\boldsymbol{P_d}$ under higher traffic load. This is due to the fact that under DPRMA, UTs will estimate the BS' received SIR for their packets and transmit in the good channels that satisfy the SIR requirement. Under high traffic load, the number of UTs to use these good channels to send their first voice packets becomes more. Thus, a voice packet can be easily dropped as a result of high contention level. With CR, FPRMA has about the same $\boldsymbol{P_d}$ as compared with the result without CR. This is because CR reassigns channels for the packets being interfered with and the number of available channels within a cell remains the same. Normally, all the available channels within a cell in FPRMA should be able to meet the SIR requirement for reserving a channel due to the reuse distance. This is why $\boldsymbol{P_d}$ is not affected. DPRMA-CR has lower $\boldsymbol{P_d}$ as compared with DPRMA. This is because with CR, the overall co-channel interference is reduced due to reallocation of channels for VTs experiencing high interference. And it becomes easier for a VT to find a good channel with estimated SIR greater than $\boldsymbol{SIR_{setup}}$. Then, the average time required for a VT in DPRMA-CR to find a channel is reduced, and thus $\boldsymbol{P_d}$ is reduced. Furthermore, DPRMA can select any one of the 60 channels for voice calls provided that the SIR requirement is satisfied. Furthermore, after introducing LBPT(0.5, 1) $\boldsymbol{P_d}$ for DPRMA-CR can be further reduced, but not for FPRMA-CR. Even though the $\boldsymbol{P_i}$ is reduced in FPRMA as shown in Figure 2(b), the number of channels per cell for contention is limited. Thus, the choice for the UT to select a channel for contention is not increased. However, in DPRMA, the $\boldsymbol{P_i}$ is reduced. Therefore, the UTs have more choices to select channels for contention and the $\boldsymbol{P_d}$ can be reduced. In general, DPRMA has lower $\boldsymbol{P_d}$ than FPRMA.

Figure 2(b) shows the $\boldsymbol{P_i}$ for the different schemes. The $\boldsymbol{P_i}$ for DPRMA is higher than that for FPRMA because the spatial reuse distance in DPRMA is normally shorter than that in FPRMA. Therefore, a packet can be easily interfered. As expected, the CR scheme can reduce the $\boldsymbol{P_i}$ effectively. This is because CR can switch an ongoing call from a channel with high level of co-channel interference to another channel with low interference. Our proposed LBPT(0.5, 1) scheme further reduces the $\boldsymbol{P_i}$ for FPRMA-CR because the increase in the received signal strength for a given UT at its own BS is larger than the increase in the interfering signal strength caused by other UTs in the co-channel cells. Thus, the $\boldsymbol{P_i}$ can be improved greatly. However, LBPT does not reduce $\boldsymbol{P_i}$ for DPRMA-CR. This is because the distance between the desired cell and the co-channel cells is closer in DPRMA whereas the distance is longer in FPRMA due to a fixed co-channel reuse distance. Therefore, with the current LBPT parameter combination (0.5, 1) the increase in the received signal strength for a given UT at its own BS is smaller than the increase in the interfering signal strength caused by other UTs in the co-channel cells. Thus, $\boldsymbol{P_i}$ in DPRMA is increased slightly. In summary, the overall effect of LBPT is: (1) under FCA, LBPT helps reduce $\boldsymbol{P_i}$ without affecting $\boldsymbol{P_d}$; (2) under DCA, LBPT helps reduce $\boldsymbol{P_d}$ while increasing $\boldsymbol{P_i}$ slightly. As a result, the voice traffic capacity is improved as shown in Table 2.

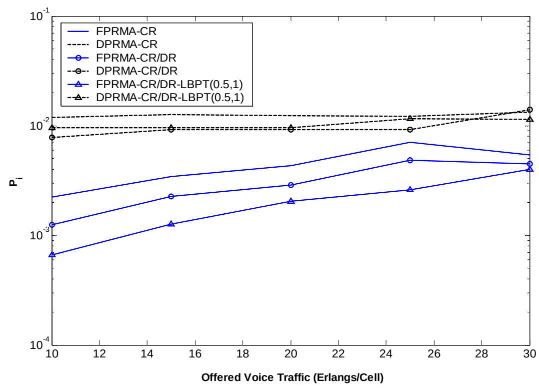
6.4.2 VDI Traffic with DR

In order to investigate the effect of channel reservation for DTs, we compare the results obtained from the schemes with and without data channel reservation (DR). We denote FPRMA-CR and DPRMA-CR with DR as FPRMA-CR/DR and DPRMA-CR/DR, respectively. Similarly, after adding the LBPT scheme, we have FPRMA-CR/DR-LBPT(0.5,1) and DPRMA-CR/DR-LBPT(0.5,1). A higher data traffic load of $\boldsymbol{\lambda_d}$ = 5 message/second and voice traffic load varying from 10 Erlangs to 30 Erlangs are considered. It is obvious that the voice traffic capacity will be lowered when there is data traffic in the system. We have selected a high data traffic load purposely in order to study the effect of DR.

The $\boldsymbol{P_d}$ for the six schemes is shown in Figure 3(a) and $\boldsymbol{P_i}$ is Figure 3(b). In Figure 3(a), the $\boldsymbol{P_d}$ for FPRMA and DPRMA with DR is lower than those without DR for $\boldsymbol{\rho}$<24 and 20 Erlangs, respectively. This is because for lower $\boldsymbol{\rho}$, the system has more available channels to allow a DT to reserve a channel for data transmission. However, for high $\boldsymbol{\rho}$, by allowing DR, there is not enough channels for a VT to contend for a channel and thus, the $\boldsymbol{P_d}$ is increased. LBPT does not affect much for FPRMA as similar to Figure 2(a). LBPT also does not affect much for DPRMA because the $\boldsymbol{P_i}$ is not changed much as shown in Figure 3(b).



(a)



(b)

Figure 3 *P_d and P_i with VDI traffic with DR*

In Figure 3(b), FPRMA without DR has higher $\boldsymbol{P_i}$ because without DR, the DT will contend randomly in any available channel for each data packet. Thus, the number of contention is increased and it will cause more interference to VTs. However, DPRMA without DR does not increase $\boldsymbol{P_i}$ too much because DPRMA has more channels to choose from. Similarly, LBPT lowers $\boldsymbol{P_i}$ in FPRMA, but not in DPRMA as explained in Figure 2. It is also noticed that the $\boldsymbol{P_i}$ for DPRMA schemes increase gradually with $\boldsymbol{\rho}$. This is because under DPRMA, UTs always search for an available channel sequentially from the lowest-numbered channel in order to increase the spatial reuse of the spectrum. Thus, the distances among UTs using the same channel are normally shorter and the talkspurts will be easily interfered with by out-of-cell UTs at any $\boldsymbol{\rho}$. Therefore, the $\boldsymbol{P_i}$ seems to be constant (actually increasing gradually) with $\boldsymbol{\rho}$. This also gives the reason why our proposed LBPT scheme does not improve the DPRMA schemes in terms of $\boldsymbol{P_i}$.

Table 2 *Voice Traffic Capacity*

	P_d=1% & P_i=1%		P_d=1% & P_i=2%	
Schemes	$\lambda_d = 0$	$\lambda_d = 5$	$\lambda_d = 0$	$\lambda_d = 5$
FPRMA	<15		<15	
DPRMA	<15		<15	
FPRMA-CR	30.3	26.6	30.3	26.6
DPRMA-CR	36.6	<10	36.6	31.7
FPRMA-CR/DR		26.7		26.7
DPRMA-CR/DR		26		31.5
FPRMA-CR-LBPT(0.5,1)	31.7		31.7	
DPRMA-CR-LBPT(0.5,1)	38.9		38.9	
FPRMA-CR/DR-LBPT(0.5,1)		30.6		30.6
DPRMA-CR/DR-LBPT(0.5,1)		21.6		27.7

The voice traffic capacity is summarized in Table 2. With voice-only traffic, the capacity for both FPRMA and DPRMA is less than 15 Erlangs. It can be seen that schemes with CR performs better than those without CR. Then, LBPT can further increase the capacity. In general, DPRMA outperform FPRMA with voice-only traffic.

With high data traffic, DPRMA performs worse than FPRMA due to high interference in DPRMA as shown in Figure 3(b). The voice capacity of DPRMA is highly limited by the $\boldsymbol{P_i}$. If 2% is used instead of 1% for the threshold $\boldsymbol{P_i}$ value as shown in Table 2, the voice traffic capacity will be increased greatly. However, DPRMA with LBPT still performs worse than FPRMA with LBPT. This may be due to non-optimized parameters combination used in LBPT.

As shown in Figure 4, the $\boldsymbol{D_m}$ is reduced significantly when DR is employed in the PRMA schemes. For FPRMA-CR/DR, for voice traffic load $\boldsymbol{\rho}$<20 Erlangs, the message transfer delay is around 0.09 seconds. When voice traffic goes beyond 20 Erlangs, $\boldsymbol{D_m}$ increases gradually and it is still smaller than 0.2 seconds at $\boldsymbol{\rho}\approx$25 Erlangs. However, $\boldsymbol{D_m}$ increases sharply for FPRMA-CR (without DR) for $\boldsymbol{\rho}$>25 Erlangs. This is because FPRMA has low stability, both the performance for voice subsystem and data subsystem degrade a lot when operating in the unstable region. But with DR, FPRMA becomes more stable because once a DT gets a channel; the message can be transmitted completely within a reasonable time. DPRMA-CR/DR gives a lower $\boldsymbol{D_m}$. With the use of DR, $\boldsymbol{D_m}$ can be reduced by almost 50%. It can be seen that our proposed DPRMA scheme provide higher stability because $\boldsymbol{D_m}$ will not be increased sharply after certain traffic load. With the proposed LBPT scheme, the $\boldsymbol{D_m}$ for FPRMA scheme can be further reduced, while it does not help the DPRMA due to non-optimized parameters combination used in LBPT for DPRMA.

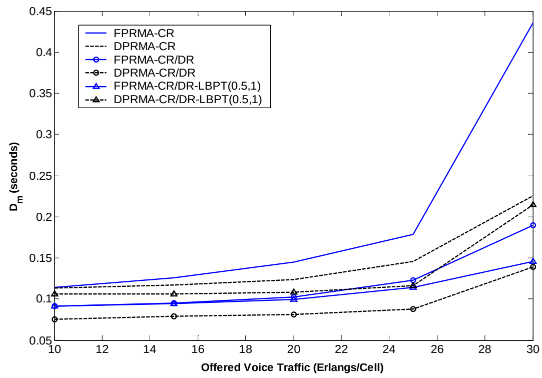


Figure 4 *D_m with VDI traffic with DR*

7 CONCLUSIONS AND FUTURE WORK

In this paper, we have investigated the performance of PRMA system in an interference-limited environment with FCA and DCA schemes. First, we propose a measurement-based DCA scheme with PRMA. Next, with careful study of the SIR levels of PRMA schemes, we propose a location based power transmission scheme to improve the SIR for a UT's transmission. Furthermore, channel reassignment is also employed to reduce the high interference probability generated by co-channel interference. Lastly, channel reservation for DTs is also investigated. Through computer simulations, with voice-only traffic, for voice traffic capacity, FPRMA-CR improves more than 100% as compared to FPRMA. An additional 21% increase in the system capacity can be obtained by using DPRMA-CR as compared with FPRMA-CR. With LBPT, the capacity improvements of FPRMA-CR-LBPT(0.5, 1) and DPRMA-CR-LBPT(0.5, 1) over FPRMA are more than 110% and 150% respectively. With voice-data-integration traffic, CR can again improve the performance. LBPT can improve the performance for FPRMA, but not for DPRMA due to non-optimized parameters combination used in LBPT. It is shown that the capacity of DPRMA schemes with VDI traffic is limited by the threshold $\boldsymbol{P_i}$ value. If we set $\boldsymbol{P_i}$ = 2% instead of 1% the capacity of DPRMA can be increased significantly. We also notice that our proposed LBPT scheme involves a trade-off between an increase on the desired signal strength and the increase on the interference caused by other UTs in the co-channel cells. A thorough study on the performance of LBPT should be conducted before applying in a wireless system. Also, the combination of (r/R, δ) = (0.5, 1) used in the simulation may not be optimum. The selection of the optimal combination (r/R, δ) for different scheme has been left as part of our future work on these schemes.

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