

The Performance of a Speech-Data PRMA System in an In-Building Environment

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Abstract: The performance of an in-building speech-data PRMA system employing frequency reuse is determined via computer simulation. Recent propagation measurements made in the building in which the PRMA system is assumed to operate, are included in the analysis. Significant variations in performance are found to exist over the coverage area. Optimum system performance is obtained by allocating the entire bandwidth to each floor (i.e., complete frequency reuse) and re-transmitting any packets that are corrupted by cochannel interference. This significant result suggests that packet access schemes such as PRMA can provide an alternative to TDMA and CDMA based future wireless networks.

I. Introduction

The development and analysis of protocols that allow terminals to efficiently transmit packetised speech and data information in a wireless environment was motivated by Goodman in [1], where he proposed the Packet Reservation Multiple Access (PRMA) scheme. The performance of both speech and joint speech-data PRMA systems has already been determined in interference-free single cell architectures [2-6]. The performance of PRMA in interference-limited outdoor cellular systems has been determined in [7-9].

In this paper the performance of an in-building speech-data PRMA system employing frequency reuse is determined from computer simulation. In particular, it is assumed that the system operates in the School of Engineering tower block at the University of Auckland, New Zealand. A recent indoor propagation study within this building produced a database of measured link attenuations for a large number of transmitter-receiver paths [10]. This database is used in this investigation to predict the power received from a range of desired and interfering user locations and to estimate the performance of the system at various locations. A floor-wide propagation model which accounts for distance dependent pathloss, floor attenuation, lognormal shadowing, and Rayleigh fading is also considered. The parameters used in this floor-wide model have been obtained from the measurements of [10]. In this paper, the differences between floor-averaged and local-region performance estimates are highlighted. From this comparison it is clear that system planners must be careful when assessing indoor systems based on floor-averaged performance

estimates, due to the significant variations in performance that exist over a floor. Also in this paper, a comparison of PRMA systems with and without speech packet retransmission is made. Such retransmission may be employed when reserved speech packets suffer corruption from cochannel interference. Significant performance variations are found to exist between these two approaches.

The remainder of the paper is organised as follows. Section II briefly describes the PRMA protocol and associated performance measures. Section III presents details of the building in which the system is considered to be operating. Section IV details the propagation measurements and propagation model used in this study. Section V presents the results of the indoor PRMA performance study in terms of packet loss probability, data packet delay and throughput.

II. PRMA Protocol

PRMA is a Time Division Multiplex (TDM) based multiple access protocol in which the transmission time scale is organised into frames, each frame containing N timeslots of duration τ seconds. Information is exchanged between terminals and base stations as packets, with no more than one packet being transmitted from a particular terminal in a given timeslot. Speech terminals generate bursts of packets corresponding to talkspurts whereas data terminals generate packets randomly. The speech and data traffic models used here are the same as those presented in [5]. Speech and data terminals recognise timeslots as being either available or reserved. Terminals with new information contend for access during available timeslots. Permission to transmit during an available timeslot is granted if the output of the terminal's uniform random number generator is less than or equal to the permission probability, where the speech permission probability p_s , is normally greater than the data permission probability p_d . When a speech terminal contends successfully, it obtains a reservation for exclusive use of that timeslot in subsequent frames until it has no more packets to transmit. Data terminals on the other hand, must contend each time that they have a packet to transmit. If a contending speech or data packet is unsuccessful in capturing the base station, the terminal involved may retransmit the packet in a future available timeslot. Speech packets, however, cannot be held at a speech terminal indefinitely due to the delay requirements of

speech. Therefore, in PRMA any speech packet held beyond a certain number of slots is dropped by its terminal. The probability of speech packet dropping is denoted by P_{drop} . Data packets, on the other hand, are retransmitted until successful, due to their stringent error requirements which do not allow them to be dropped. The key performance measure for data packets is W , the mean data packet delay. When a reserved speech packet is transmitted by a speech terminal to its base station, it is possible that the packet will be corrupted by cochannel interference. The probability of this occurring is the interference probability, P_{int} . The combination of those packets dropped plus those packets interfered is the total speech packet loss, P_{loss} , given by [8,9]

$$P_{loss} = P_{drop} + (1 - P_{drop})P_{int} \quad (1)$$

Instead of permanently losing a reserved speech packet due to interference, a speech terminal may decide to return to the contention state and obtain a new timeslot reservation in which to transmit the packet [6]. In this situation, P_{int} in (1) becomes zero while P_{drop} will increase. Systems with and without speech packet retransmission are investigated in this paper. The capacity of PRMA systems can be estimated by the number of users per floor that can be supported at a 1% speech packet loss probability. The overall system utilisation, ψ , of a PRMA system is given by $\psi = \eta / N_c$, where η is the throughput per floor and N_c is the cluster size [9].

III. System Model

It is assumed that the PRMA system operates in an indoor environment with vertical frequency reuse such that each floor is served by one base station. In particular we assume that the system operates in the School of Engineering tower block at The University of Auckland where a recent 1.8 GHz indoor propagation measurement study was performed [10]. The building has an inter-floor spacing of $h=2.9\text{m}$ and floor dimensions of $18.5\text{m} \times 18.5\text{m}$. This paper determines the performance of users on the 8th floor, which is regarded as the ‘‘central floor’’ and whose floor plan is shown in Fig. 1. The distance between the central floor base station and cochannel base stations is the frequency reuse distance, $D=hN_c$, where N_c is the cluster size. This configuration is illustrated in Fig. 2. The number of speech terminals (M_s) and data terminals (M_d) per floor is assumed to be constant for all floors. It is assumed that the central floor base station only accepts packets from terminals on its floor: packets from cochannel floors are considered to be interference.

Given that a particular timeslot on the central floor is available it is possible that μ_{cen} ($0 \leq \mu_{cen} \leq M_s + M_d$) central floor speech and data terminals may transmit their packets to the central floor base station. For convenience, one out of the μ_{cen} central floor transmitting terminals is denoted the ‘‘desired terminal’’ while the other $\mu_{cen}-1$ terminals are denoted the ‘‘intra-floor interferers’’. With reference to Fig. 2, the desired terminal is at

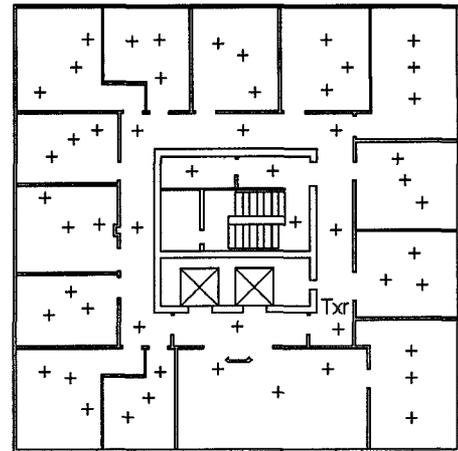


Fig. 1: Typical floor plan for the School of Engineering tower block. Markers (+) indicate measurement locations.

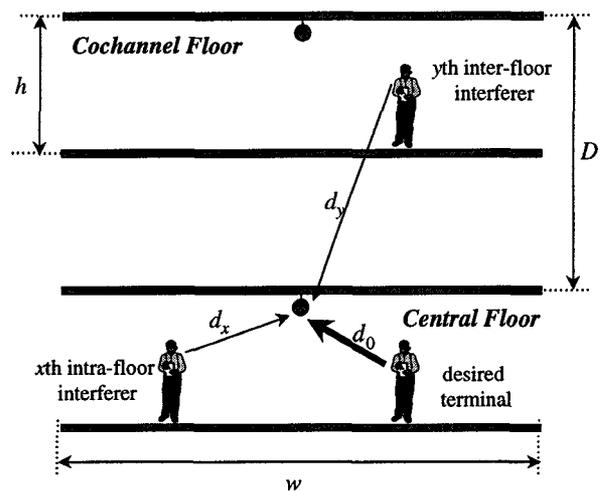


Fig. 2: Sources of interference in indoor PRMA.

— Desired Signal — Interfering Signals

a distance d_0 from the central floor base station while the x th ($0 \leq x \leq \mu_{cen}-1$) intra-floor interferer is at a distance d_x . In addition to the central floor terminals that transmit in an available timeslot, μ_{coc} ($0 \leq \mu_{coc} \leq 2(M_s + M_d)$) speech and data terminals on cochannel floors may also transmit. Here we only consider interference from one cochannel floor above and below the central floor. These speech and data terminals are denoted as ‘‘inter-floor interferers’’. The y th ($0 \leq y \leq \mu_{coc}$) inter-floor interferer is located at a distance d_y from the central base station. All terminal antennas are assumed to be at height $h/2$.

IV. Propagation Model

A floor-wide propagation model similar to that described in [11] is adopted in this study, although Rayleigh fading is also included. The momentary power received at the central base station from a terminal at a path length, d , is therefore given by

$$P = \frac{d^{-\beta} \cdot \alpha^2 \cdot e^{\xi}}{FAF} \quad (2)$$

where β is the propagation exponent, FAF is the cumulative floor attenuation factor expressed in linear units, e^{ξ} represents the lognormal shadowing, having a standard deviation $\sigma = \ln(10) \cdot \sigma_{dB} / 10$, and α is Rayleigh distributed with unit mean. Both β and FAF depend on the number of floors separating the transmitter and receiver. Values of β , FAF and σ_{dB} , derived from the University of Auckland indoor propagation study [10] are presented in Table 1. These parameter values are calculated from floor-wide averages of the propagation measurements.

Table 1: Propagation parameters [10].

Floors, k	FAF [dB]	σ_{dB} [dB]	β
0	0.00	9.6	4.8
± 1	16.0	9.8	4.8
± 2	22.1	8.5	4.8
± 3	29.0	7.9	4.8

By applying the floor-wide model, the variability of a signal from an individual terminal is implicitly assumed to be equal to the signal variability measured over the entire floor. However, this assumption is only valid if a terminal moves over a significant percentage of floor locations. In reality, terminals are likely to be confined to localised regions, for example to a single office. The results of the Auckland indoor propagation study have confirmed that the shadowing variability over a single office is considerably less than the variability measured over the entire floor. The overestimation of shadowing results in a pessimistic system performance prediction at some locations and an optimistic prediction at others. An alternative approach to using (2), is to use the actual database of propagation measurements presented in [10]. This database contains the measured local mean power at a large number of floor locations. It is therefore possible to predict the momentary power at a measurement location using $P = \bar{P} \cdot \alpha^2$, where \bar{P} is the measured local mean power and α represents the Rayleigh fading that was observed at the majority of measurement locations.

Due to the random nature of the indoor propagation channel, packets will be received at the central base station with varying power levels. In the event of a collision, the packet with the greatest power still may be received at the receiver due to the capture effect. The desired packet is considered to capture the central base station if its momentary power, P_0 , exceeds the momentary composite interference power, P_I , by a specified capture ratio, z , where the composite interference power is given by

$$P_I = \sum_{x=1}^{\mu_{cen}-1} P_x + \sum_{y=1}^{\mu_{occ}} P_y \quad (3)$$

The appropriate capture probability expression, assuming the floor-wide model, was presented in [12].

V. Results & Discussion

The results presented in this section have been obtained from a computer simulation of a realistic indoor PRMA system whereby packets transmitted on one floor affect the performance of neighbouring floors. Results are presented for the three indoor PRMA system configurations given in Table 2. The total bandwidth allocated to each system is constant to enable fair comparison, but each system has a different cluster size. In addition it is assumed that for all systems, the speech coding rate, $R_s=32\text{kb/s}$, the data coding rate $R_d=2.4\text{kb/s}$, the packet size is 640 bits (64 bits header, 576 bits information), the speech packet delay limit, $D_{max}=36\text{ms}$, the speech permission probability, $p_s=0.3$, while the data permission probability, $p_d=0.07$. In addition, the capture ratio, $z=10\text{dB}$, the mean talkspurt duration, $t_1=1.00\text{s}$, while the mean silence duration, $t_2=1.35\text{s}$.

Table 2: Pico-cellular PRMA system parameters.

Cluster size, N_c :	1	2	3
Total channel rate, R_T (Mb/s)	1.28	1.28	1.28
Channel rate/floor, R_C (Mb/s)	1.28	0.64	0.4267
Frame duration, T (ms)	18	18	18
Slots/frame, N (each floor)	36	18	12
Slot duration, τ (ms)	0.5	1.0	1.5

Fig. 3 plots the packet loss probability for speech only systems with and without packet re-transmission. The results presented in Fig. 3 are based on the floor-wide propagation model. It is clear that for the particular parameters chosen, PRMA operation in an indoor environment is impossible without packet retransmission. This is due to the level of inter-floor interference that exists in such an environment. Increasing the cluster size improves the performance of those systems with no speech retransmission, but degrades the performance of systems with speech retransmission. When $N_c=1$, more timeslots are available to terminals, compared to $N_c=2$ or $N_c=3$, so that speech packet retransmission does not impose a serious level of congestion on the system. Re-using the spectrum on each floor and employing retransmission is therefore the best option.

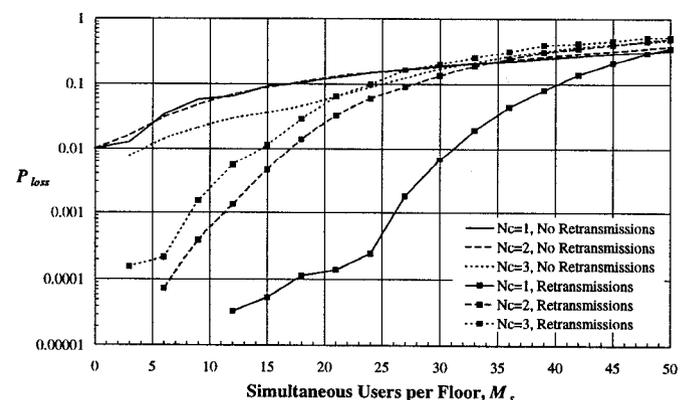


Fig. 3: Packet loss probability, speech only systems.

Of interest to system planners are the performance variations that exist over the coverage area. Figs. 4 and 5 plot the variation in packet loss probability over the central floor for speech only systems with $N_c=1$ and $M_s=40$ users/floor, and with and without speech packet retransmission. For this particular building, the central core has a significant effect on the performance at certain locations. In particular, terminals in the shadow region of the floor (opposite side from transmitter) experience significantly worse performance compared to terminals on the same side as the transmitter. Clearly this information is unavailable in the floor-averaged results of Fig. 3. An appreciation of these performance variations is especially relevant in indoor systems, where users are normally confined to a single area (e.g., office room) permanently or semi-permanently. In this situation, users could conceivably experience consistently good or consistently bad communication, depending on their location.

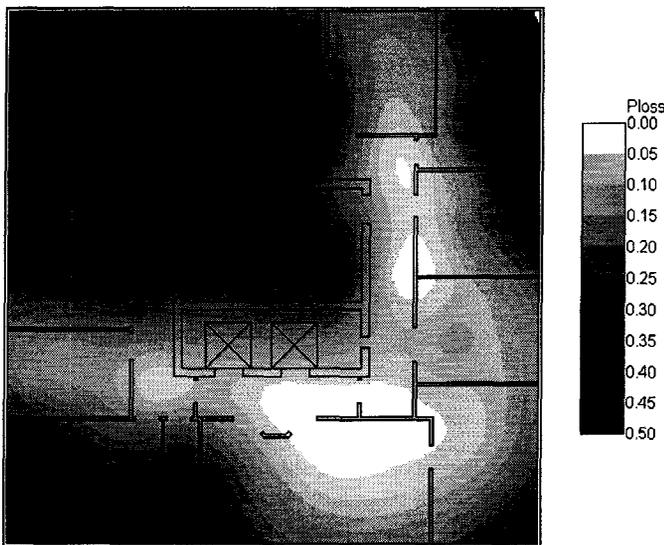


Fig. 4: Packet Loss Probability, $M_s=40$ users/floor, $N_c=1$, no speech packet retransmissions.

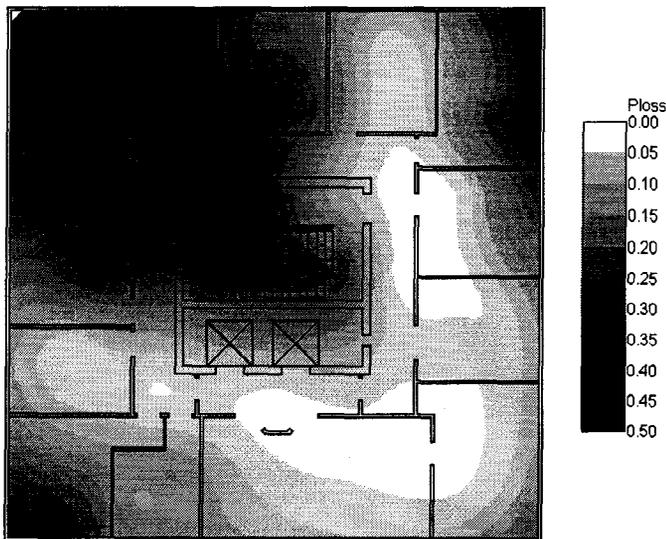


Fig. 5: Packet Loss Probability, $M_s=40$ users/floor, $N_c=1$, speech packet retransmissions.

Fig. 6 plots the cumulative distribution function of the P_{loss} contours in Figs. 4 and 5. It is clear that speech packet retransmission improves the performance of speech terminals over the entire floor although analysis has shown that the improvement is considerably greater for terminals in the non-shadowed region of the floor, with terminals there experiencing approximately a 75% reduction in P_{loss} . Nevertheless, terminals in the shadowed region obtain up to a 30% reduction in P_{loss} with packet retransmission. The average reduction in P_{loss} over all locations is 54%.

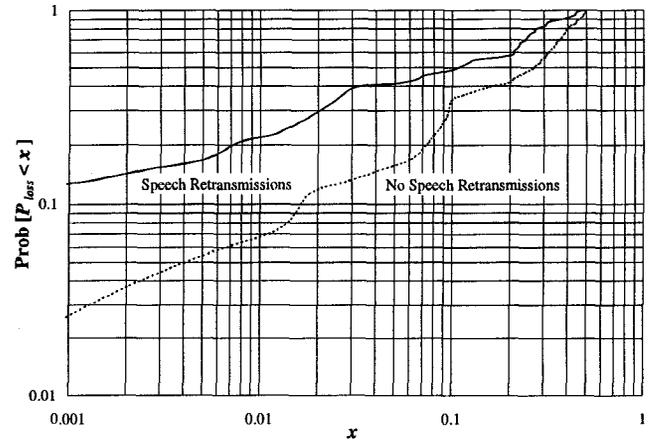


Fig. 6: CDF of P_{loss} , speech only systems, $M_s=40$ users/floor, $N_c=1$.

The effect of additional data terminals in the indoor PRMA system is an important design consideration. Fig. 7 plots the packet loss probability for speech-data PRMA systems with and without speech retransmission and compares these results with those obtained for identical speech only systems. In the speech-data systems, the number of data terminals, M_d , is equal to the number of speech terminals, M_s . It is clear that the additional intra- and inter-floor interference contributed by the data terminals degrades the performance of the speech terminals in terms of packet loss probability.

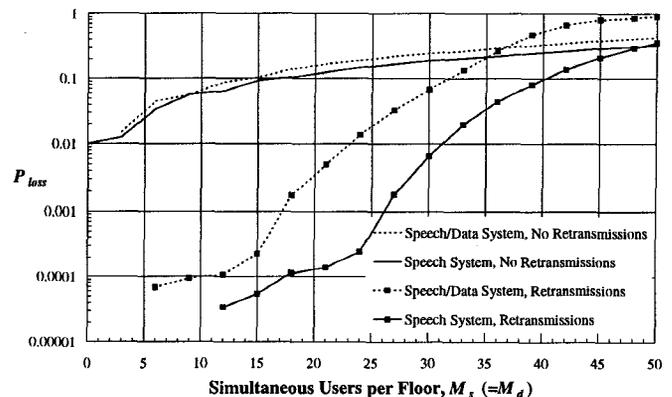


Fig. 7: Packet loss probability, speech only versus speech-data systems, $N_c=1$.

Fig. 8 plots the packet delay, W , for the three indoor speech-data PRMA systems. Increasing the cluster size increases the

amount of time that data packets are delayed. This is due to a reduced number of timeslots/frame available for packets to be transmitted in. From the perspective of data terminals, a cluster size of $N_c=1$ is ideal (as was true for speech users).

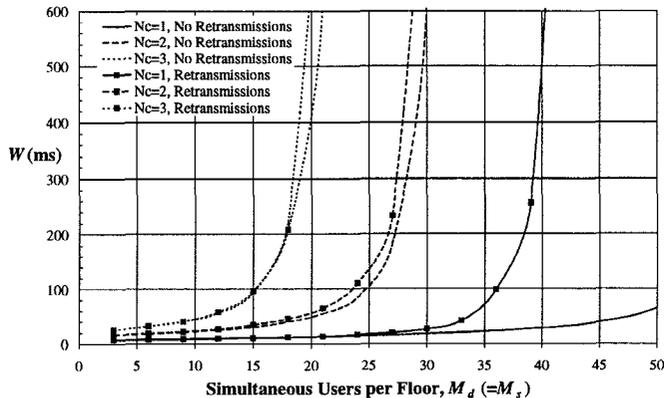


Fig. 8: Average data packet delay, speech-data systems.

Table 3 summarises the principal results of this paper. All of the results in Table 3 are based on systems that employ speech packet retransmission: without retransmission, the system capacities are significantly lower. From these results, the best scenario for both speech only and speech-data systems is to reuse the entire frequency spectrum on each floor, i.e. $N_c=1$. However, it is essential that speech packet retransmission also be included in order to overcome the effect of increased inter-floor interference which results. A similar finding was presented in [13] for CDPA (Capture Division Packet Access) where it was found that abating cochannel interference by random retransmission was more effective than spatial isolation of cells using the same channel, as is usual in FDMA/TDMA systems.

Even for a PRMA system with $N_c=1$, the performance is not as good as has often been suggested in the literature, (e.g. [5]) due to the presence of cochannel interference. The performance of multiple cell PRMA systems may approach those predicted for single cell systems if additional interference reduction and/or cancellation techniques, such as those presented in [9] are also included.

Table 3: Indoor PRMA performance analysis of systems incorporating speech retransmission. Performance measured using $P_{loss}=1\%$ criterion.

	Speech Only			Speech-Data		
	1	2	3	1	2	3
Users/floor, $M_s (=M_d)$	31	17	14	23	13	12
Data Packet Delay, W (ms)	-	-	-	15	29	57
Throughput/ floor, η	0.35	0.36	0.49	0.30	0.34	0.48
System Utilisation, ψ	0.35	0.18	0.16	0.30	0.17	0.16

VI. Conclusion

The study of PRMA in an in-building pico-cellular environment has revealed that significant variations in user performance exist depending on a user's location within the building. If speech packet retransmission is not employed, PRMA suffers from a high packet loss probability, which is particularly bad in systems with small cluster sizes. However, if speech terminals are allowed to retransmit interfered packets, smaller cluster sizes (and in particular $N_c=1$), actually provide the optimum performance for both speech and data terminals. This is due to a significant increase in the number of channels per floor, which outweighs the additional traffic contributed by speech packet retransmissions. It is likely that complete frequency reuse and packet retransmissions would also prove ideal for an outdoor cellular PRMA system. While the results obtained in this paper for a multi-cell system are not as favourable as for a single cell system, it is expected that comparable performance could be obtained through the use of interference reduction techniques.

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