

A PILOT BASED DYNAMIC CHANNEL ASSIGNMENT SCHEME FOR WIRELESS ACCESS TDMA/FDMA SYSTEMS

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Abstract

We propose a control architecture for implementing a dynamic channel assignment (DCA) algorithm which optimizes two-way channel quality in a TDMA portable radio system.

A common control frequency, which is frame-synchronized among base stations, provides (1) beacons for portables to locate base-stations and obtain DCA information, (2) broadcast channels for system and alerting information, and (3) pilot signals to permit portables to evaluate downlink interference. This allows low-complexity radio ports and portables to simultaneously select channels to avoid interference and avoid creating excessive interference. Only local measurements are needed for this autonomous DCA scheme, thus avoiding processing by a centralized controller or communications among distributed controllers. A superframe structure on the control frequency provides redundant information for the beacon and pilot signals to avoid the "blind-slot" problems which cause significant difficulty in other systems for the link transfer (hand off) process.

Results from computer simulations demonstrate the good spectrum efficiency of this method. They also show that power control further improves the performance significantly.

This work is targeted towards understanding the implications to local exchange networks of wireless system alternatives that could provide access to those networks.

1. Introduction

Dynamic Channel Assignment (DCA) in a variety of forms has been proposed for TDMA wireless systems as well as for FDMA systems. [1] [2] [3] [4] [5] [6] [7] The proposed system architectures are limited in their ability to perform automatic link transfer to maintain the quality of their circuits.[8] This paper considers DCA in the framework of wireless systems using a combination of TDMA and FDMA. In the remainder of the paper, reference to TDMA will imply frequency division also, i.e., TDMA/FDMA.

TDMA wireless access systems have a number of potential advantages^[9] including continuous alternative channel measurements by active portables, Performing measurements for Automatic Link Transfer (ALT or handoff) at portables provides a number of advantages including,

- Making all measurements by a single receiver and thereby reducing the impact of errors in measurements,^[9]
- Reducing network signaling,
- Permitting ALT radio signaling on the new radio link instead of the old degraded radio link and thereby reducing dropped calls.

High performance ALT is critical to maintaining call quality in a large system, and ALT stresses DCA schemes when practical implementation constraints are considered. The organization of a TDMA radio system to provide high performance DCA while performing ALTs is the topic considered herein.

DCA removes the requirement for fixed structured frequency reuse for traffic channels. All traffic radio channels (combinations of time-slots and carrier frequencies) are available everywhere for every call. A DCA algorithm is used on a call-by-call basis to achieve time-varying frequency reuse patterns. DCA has the potential to efficiently reuse limited radio spectrum by statistically multiplexing radio channels among a cluster of radio ports. However, it also demands periodic accurate measurements of all radio channels, which are rapidly changing and do not have a fixed spatial distribution.

Using DCA algorithms to select communications channels as needed, TDMA or FDMA systems can serve dynamic traffic demand.^[10] Under the assumption of real-time, centralized processing of interference information, Nettleton et al.^[6] have demonstrated that significant capacity improvements could be gained using this class of assignment methods compared to conventional frequency reuse. In order to relax the requirement for centralized control, we shall consider algorithms that rely only on local measurements to autonomously assign channels between individual pairs of ports and portables.

TDMA operation permits an active portable with a single receiver to make signal strength measurements for ALT by briefly switching frequencies in between periodic time-slots of activity. However, a TDMA portable cannot make measurements on those time-slots during which it is active. Furthermore, low-complexity RF synthesizers require significant time to switch frequencies, and time-slots adjacent to active time-slots may be inaccessible to portables for measurements. Thus, a TDMA portable may not be able to

make measurements on a significant number of time-slots ("blind slots") to locate radio ports or to select radio channels immediately prior to an ALT. As an example, Figure 1 shows a 10 time-slot frame structure with a portable receiving in time-slot number 1 and transmitting in number 2. Due to synthesizer switching constraints, the leading and trailing time-slots, 0 and 3, are also unavailable for measurement purposes, thus the portable can only make measurements on 6 out of 10 possible time-slots.

The first significant function for DCA is the determination of a target port. The associated signals which are transmitted continuously by ports could be called beacons, because portables use them to locate the ports and in particular to determine the strongest port. A desirable feature of a TDMA system is that a portable can quickly measure the beacon signals independent of traffic conditions. This observation suggests that beacon signals should be separated from traffic channels to achieve high performance. Since an active portable is blind to a significant fraction of the available time-slots, the beacon signals should contain redundancy that includes transmitting in multiple time-slots to permit all possible active portables to measure all beacon signals.

The second significant function for DCA is the selection of a channel for communication with the target port. A common attribute of wireless equipment is the use of paired uplink (portable to port) and downlink (port to portable) channels to achieve full duplex operation. Paired channels reduce complexity in equipment and system configuration. In both DECT^[1] (Digital European Cordless Telecommunications) and Japanese PHP^[2] (Personal Handy Phone) systems, a radio port and a portable independently decide the most desirable channel on which to setup a radio link based on their own individual measurements. Since the co-channel interference in the uplink and downlink directions are different (especially when shadow fading is high), it may take several such attempts to find a channel with acceptable signal quality in both directions. This increases setup delay, and the probability of setup and ALT failure.^[7] The DCA scheme considered here selects paired channels based on interference measurements at both receiving ends of a full duplex radio link, similar to the scheme proposed for the CT-2 Plus system^{[5] [7]} to use at access. This type of algorithms has been shown to provide significant improvement over the algorithms without a joint selection process.^[7]

The interference measurement process at a portable for channel selection is separate from that for selecting a target port by measuring beacon signals. The former involves the measurement of active traffic channels which may include power control, while the latter involves measurement of non power-controlled signals designed specifically to permit accurate determination of the strongest ports by portables. Also, for interference measurements for DCA prior to an ALT, an active TDMA portable is blind to a significant number of possible time-slots. If a portable cannot consider all possible channels to access a new port during an ALT process, the achieved quality will be reduced statistically. Furthermore, ALTs may be blocked during periods of high activity if the

only available time-slots on a new port coincide with blind slots for a portable attempting an ALT. These observations suggest that pilots be transmitted by ports, in multiple time slots on a common control frequency, to indicate the occupancy of port-to-portable (downlink) traffic channels.

In the second section, we describe a pilot based DCA scheme that considers both uplink and downlink performance. This DCA scheme uses a single-frequency control-channel shared by all radio ports. The transmitted frame structures of all radio ports must be time synchronized. The control channel is shared in time, to communicate several types of information to portables.

The third section presents the results of computer simulations of a large system of portables and radio ports. The results show that pilot based DCA combined with power control and antenna diversity can achieve excellent spectrum efficiency.

2. A Pilot Based DCA Scheme

The pilot based DCA scheme described in this section is based on low-delay TDMA wireless access techniques proposed by Bellcore.^[11] The same methodology can be applied to other TDMA systems.

2.1 General Requirements and Structure

The proposal is based on TDMA with 10 time-slots in a 2 millisecond frame, a channel transmission rate of 500 kbps, and QPSK modulation. Channel spacing would be about 400 KHz. Downlink and uplink traffic channels are assigned to paired frequencies in adjacent time-slots. For the DCA architecture, the proposal has 10 traffic frequencies and a control frequency. Thus, about 5 MHz of spectrum is required for uplink channels and another 5MHz is required for downlink channels. An additional requirement for including DCA is that the timing of the frame structures of all fixed radio ports (base stations) must be synchronized. This implies that (1) any timing (phase) errors must be small compared to a time-slot and (2) these errors can be accommodated by the guard time between bursts. A combination of several techniques can be used to synchronize port frame structures.^{[12] [13]}

To avoid the requirement for a frequency diplexer, portables transmit and receive on adjacent time-slots. Portables are also permitted to take one time-slot to change frequencies. As detailed in Figure 1, when a portable is active, it can only make measurements on 6 time-slots out of 10. Figure 2 illustrates the portable's frame structure. Beacon or pilot information is repeated in time-slots 0 and 5, thus a portable can always monitor one of these two slots while communicating with a port. Figures 3 summarize the frame structures from port's perspective. Other details for these two figures are discussed later.

As briefly discussed in Section 1, *every port* must provide beacon signals and *every active channel* must be indicated by the pilot signals. All these beacon and pilot signals must be multiplexed on the control frequency. In order to achieve these objectives, we use a superframe consisting of 200 frames

to provide: (1) beacons for all ports in the odd-number frames and (2) pilots for all channels in the even-number frames. Figure 4 is the superframe structure indicating interleaving of beacon and pilot frames. This results in a 400 millisecond measurement updating period.

2.2 Beacons

Referring to Figure 4, each port chooses 1 set of 4 periodic frames from 25 sets of 4 frames each to transmit (at constant full power level) beacon information with identical information transmitted in time-slots 0 and 5 of each of the 4 frames. This results in each port transmitting beacon information on the downlink control frequency every 100 milliseconds. All portables measure the signal strengths of the beacons and select the strongest port for communications purposes. In addition, all portables obtain information by demodulating and decoding the beacon bursts. The information includes system ID and a short list (described later) of the ports' preferred channels. Twenty-five sets of unique beacon time-slots allow the beacon signals to be reused with acceptable co-channel interference. The assignment of these beacon time-slot sets could be performed by autonomous distributed techniques to reduce operational requirements by system operators.^{1 [14] [11]}

The reverse beacon channels, i.e., corresponding time-slots on the uplink control frequency, are proposed to handle ALT requests by portables. This provides opportunities for portables to make ALT channel requests once every 100 milliseconds. Since the reverse beacon channel exists on time-slots 0 and 5, an active portable can always make an ALT channel assignment request to a new port without dropping any voice or data frames with the old port.

2.3 Pilots

Figures 2-4 also indicate that time-slots 0 and 5 in the even-number frames of a 200-frame superframe contain pilot signals which map the 100 traffic channels (10 traffic frequencies x 10 time-slots/frequency) onto the control frequency. If a port is active on a traffic channel, then it transmits an RF pilot signal (at the same power controlled level as that of the active traffic channel) on the control frequency in time-slots 0 and 5 of the designated frame. Similarly, time-slots 0 and 5 contain identical information, so that all active portables are able to make measurements corresponding to the interference on all of the 100 possible traffic channels.²

1. Note that no reuse pattern is required for the pilot channels since they are used only to indicate occupancy for measuring interference and are not intended to be demodulated.

2. Measurements on the control frequency yield accurate estimation of local mean interference on the actual traffic channels. The errors resulting from the instantaneous interference fluctuations are small because of antenna diversity and time averaging.

2.4 DCA procedures

The DCA procedures are summarized in Figure 5. In this DCA proposal, a fixed radio port measures the received power on all possible traffic channels on which it is not currently active. The radio port chooses about 6 of the channels having the lowest received power^[7] (typically any of these would provide a good channel from the port's perspective for a new call). It broadcasts this short list on its beacon channel to portables for use in selecting a channel for a new call or an ALT from another port. The short list does not include any channels which are in use for traffic or control purposes. The portable makes measurements on the pilots corresponding to the downlinks of the traffic channels on the short list, and it chooses as the final paired communications channel that channel with the lowest measured power. In this manner, both the port and the portable provide significant input into the distributed DCA algorithm to select channels with low interference on both the uplink and downlink.

2.5 System Broadcast Channel

As shown by Figures 2-4, each port also transmits System Broadcast Channel (SBC) information,^[15] including paging (ringing) information, on the control frequency. The SBC information is contained in a third time-slot (other than time-slots 0 and 5) in every fourth frame, resulting in a signaling capacity of 8 kbps which is adequate for a substantial volume of paging.^[16] Similar to the beacon slot, the SBC slot could be autonomously determined by each port. Since the SBC channel is received by portables only when they are not in active service, redundancy is not required to avoid portable blind-slots. Assuming a port contains a single transceiver, 2 time-slots per frame are dedicated to beacon/pilot purposes (time-slots 0 and 5). Thus, 8 time-slots per frame can be used for SBC purposes throughout a system, permitting up to 32 possible SBCs based on using only every fourth frame. Initial access requests could be processed on the reverse SBC which has substantial capacity.

This arrangement permits a single transceiver port to provide 7 traffic channels while providing beacon, pilot, SBC functions, initial access requests and ALT requests all on a common control frequency pair which is shared in time and time synchronized with all other ports. A 2-transceiver port could provide 17 traffic channels, i.e., 7 traffic channels and control functions on one transceiver and 10 additional traffic channels on the second transceiver.

An important novelty in this proposal is the implementation of a single-frequency control-channel shared in time by all base stations (which are time-synchronized). This control-channel avoids blind-slot problems and permits DCA algorithms that use measurements made at both ports and portables to minimize interference.

3. System Performance Results

Some of the references on DCA methods focus on systems with a high number of radio ports, each with low occupancy (defined as the fraction of time-slots that are active) on average.^{[1] [3]} Although the total system capacity (in Erlangs

per unit area) is very high, these systems do not utilize radio ports efficiently. We therefore consider higher occupancy, on the order of 60%. On average, 4 slots are active for ports with one transceiver (7 traffic slots), and 10 slots are active for ports with two transceivers (17 traffic slots). We simulated the SIR (signal to co-channel interference ratio) at access and blocking probability (P_B). The SIR considered is a snapshot at the instant of access and no subsequent movement or ALTs are simulated. In a real system, ALTs will maintain signal quality at about this level, but the resultant system dynamics require further study. The P_B considered is due to blocking of traffic slots only, blocking due to insufficient SIR, and contention for link setup and ALT control is not simulated.

Trade-off between SIR and P_B are studied for cases where every port has either one or two transceivers. We also simulated cases with or without power control. *The power control algorithm considered here compensates only for signal variations due to distance-dependent path loss and shadow fading.* A feedback power control algorithm that tracks small-scale fading and approximately maintains a desired instantaneous SIR^[17] will result in even further improvement in system SIR.^[18]

3.1 System Model

We consider a two-dimensional square service area with 256 ports placed in equally spaced 16X16 regular grid locations.^[14] Each port transceiver has 10 TDMA time-slots, each can be used on any one of 10 traffic frequencies or the control frequency.

Traffic arrival is a finite-source quasi-random process which approaches a Poisson process. Call holding times are exponentially distributed. Mean call arrival and departure rates are uniform in the entire service area; the ratio of two rates can be adjusted for different levels of traffic occupancy.³ The incoming traffic is generated by 40,000 portables which are located at 200X200 equal-spaced square grid points in the service area. By randomizing the arrival sequence, the spatial traffic loading is uniform on the average. We consider different loading levels to test the traffic capacity for ports with either one or two transceivers.

We assume each portable monitors beacon slots to select the port with the highest local mean power (averaged over Rayleigh fading).⁴ This process would need to be updated periodically as a portable moved from one position to another. However, it is simulated only once, upon the portable's arrival, since we did not consider user's movement or link transfer. If idle slots are available, the accessed port and

portable jointly select the time slots and frequency pair according to the DCA algorithm described above.

3.2 Propagation Model

We considered the co-channel interference-limited case and ignored the contribution of noise by assuming sufficient signal coverage in the service area. Many propagation models have been reported for representing co-channel interference in wireless access communications.^[19] We consider a model that is applicable for ports placed outdoors to serve the users in and around houses in residential areas.^[20] In the model, the average received power decreases with distance d as d^{-4} and the large-scale shadow-fading distribution is log-normal with a standard deviation of 10 dB. Rayleigh fading is included as an option to account for small-scale variations. When two branch selection diversity was used to mitigate Rayleigh fading in the channel selection process, we found that the performance is within about 2 dB of the performance achieved by assuming Rayleigh fading is averaged out in channel selection. We thus did not include Rayleigh fading for the results to be shown.

This propagation model includes more co-channel interference compared with typical models used for indoor propagation, therefore, the SIR in the indoor environment is likely to be higher than that obtained here.

3.3 Numerical Results

Figure 6 shows cumulative distributions for local mean downlink SIR at access for the case where every port has only one transceiver that supports 7 traffic channels. At the first percentile, power control, which compensates only for the local mean signal variations, improves the performance by about 7 dB. Even without power control, the first percentile SIR is about 17 dB, which is approximately the performance of a system using structured and quasi-fixed frequency reuse with 25 frequencies.^[14] A local mean SIR of 17 dB will provide adequate circuit quality of about 2% word error rate for QPSK modulation assuming diversity reception.^[21] Improved power control which can track the slow small-scale fading in pedestrian environments^[17] and 2-by-2 diversity (2-branch receiver diversity combined with 2-branch feedback transmit antenna diversity; this technique can provide over 3 dB performance improvement beyond the performance of 2-branch selection diversity).^[22] are expected to reduce the required local mean SIR⁵ and thereby provide a significant operating margin. Considering a total of 10 traffic frequencies and 1 control frequency used for the DCA method, a significant improvement in spectrum efficiency is achieved at the expense of providing accurate time synchronization of the port transmissions. Figure 7 shows similar results for the uplink performance.⁶

3. This DCA scheme can also be applied to handle traffic hot spots, but we use a uniform traffic model to investigate its suitability for medium access control.

4. We have also simulated the case where the instantaneous power (after two-branch diversity selection) is used to select the access port. The degradation at the first percentile SIR is a fraction of 1 dB. We also considered the possibility of accessing the second or third best port in order to get higher traffic throughput for the case where every port has only 7 traffic slots.

5. For example, simulations of baseband hardware implementation of a power control method and two-branch selection diversity^[17] indicated that 15 dB local mean SIR would result in lower than 0.2% word error rate for maximum Doppler frequency up to 5 Hz.

6. Since we maintained a constant number (6) of port's preferred channels, the performance is not always balanced in both directions, depending on the number of traffic channels available. But both directions provide reasonably good SIR at the first percentile.

The disadvantage of using a single transceiver is its low traffic capacity, resulting in about 7% blocking at a level of only 4 Erlangs per port, if only the strongest port is selected. The blocking probability can be reduced to about 1% for that traffic load at the expense of 1 to 2 dB degradation at the first percentile by accessing the second best port if the best port is blocked. Selecting the second best port may be difficult if it is too far from the portable and the noise floor becomes significant. The best way to handle traffic fluctuations may be to dynamically turn on extra traffic slots provided by additional transceiver(s). However, this also increases co-channel interference.

During periods of high traffic, some ports could turn on two transceivers and provide up to 17 traffic slots. Figures 8 and 9 show downlink and uplink SIR distributions respectively, at access under the load of about 10 Erlangs per port. P_B is only about 1.4 % at that traffic load. This shows the potential of this DCA scheme to handle load fluctuations. This gain in traffic throughput results in about 6 dB of SIR degradation at the first percentile of the uplink and downlink distributions. But, the addition of power control which only compensates for local mean attenuation results in a first percentile local mean SIR of about 17 dB. This is sufficient for good link performance. Further improvement can be achieved using rapid feedback power control to track small-scale variations in radio link attenuation.^[17]

4. Conclusions

Using DCA, radio spectrum can be efficiently reused without frequency planning for traffic channels, but radio port beacons must be assigned in a semi-permanent way using a large reuse pattern to avoid interference. Increase of traffic load can also be handled by turning on additional transceivers as needed. TDMA/FDMA architecture permits portables to monitor and pre-select alternative radio links for automatic link transfer (ALT). Two major limitations of existing TDMA/FDMA DCA algorithms are: (1) existence of blind slots that cannot be monitored for ALTs and (2) lack of a procedure to optimize two-way performance before access attempts.

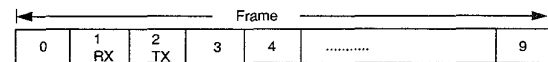
We described a pilot-based DCA method for TDMA/FDMA wireless access. Radio ports are required to be accurately time synchronized in frame structure. Using a control frequency, ports can send beacons which portables measure to select the best access port and demodulate to obtain information about the best uplink channels. Blind slots for beacons are eliminated by repeating the same beacon information every half frame. On the same control frequency in different frames, pilot signals corresponding to active traffic channels are also transmitted redundantly by each radio port. This permits portables to make rapid and complete interference measurements for the downlink channels. As a result, blind slots for measurements of traffic channel interference are also eliminated. The DCA algorithm jointly optimizes both uplink and downlink performance without centralized control.

Results from computer simulations have demonstrated good spectrum efficiency for this method and the possibility of using higher number of transceivers to handle higher traffic

demand. A significant result is that about 10 MHz of total spectrum (two 5 MHz paired bands) can support an average occupancy of ten 32 kbps circuits per radio port while maintaining adequate performance for over 99% of those circuits. Each two-transceiver radio port can support 10 active circuits on average and 17 active circuits peak with about 1% probability of blocking. The cost increased for the spectrum efficiency is precise time synchronization of all radio port transmissions.

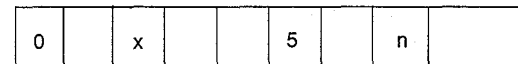
Acknowledgements

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- definition: the slots at an active portable that cannot be used to monitor alternative channels for link transfer
- slot 0: switching to traffic frequency
- slots 1 & 2: active link , RX & TX
- slot 3: switching to other frequency for monitoring
- slots 4-9: monitoring beacon and interference for alternative ports and channels
- blind slots: 0-3; non-blind slots: 4-9

Figure 1. Receive, transmit, frequency switching and signal monitoring sequence and blind slots at portable.

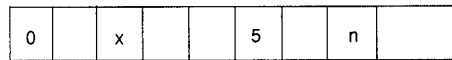


- If not active: can monitor all slots
 - monitor slots 0 and 5 for beacon/pilot to decide the best available port/channel
 - monitor slot n for SBC, $n=1,2,3,4,6,7,8,9$
- If active on slot x (RX): $x=1,2,3,4,6,7,8,9$; $x \neq n$
 - slot x-1 to switch back to traffic frequency
 - slots x+1 for TX
 - slot x+2 to switch to control frequency
 - either slot 0 or 5 is available to monitor beacon/pilot for ALT

Figure 2. Frame structure at portable.

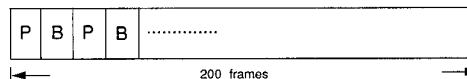
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- Slots 0 and 5 used for pilots and beacons according to the 400 msec superframe
- $n = 1, 2, 3, 4, 6, 7, 8, 9$
 - Determined quasi-statically by port measurements
 - Up to 4 ports can reuse the same n th slot for SBC every 8 msec; frequency and time reuse factor=32
- $x = 0, 5, n$ for the first transceiver
 - 7 traffic channels with single transceiver
 - 17 traffic channels with two transceivers

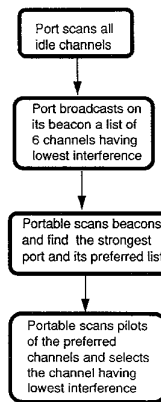
Figure 3. Frame structure at port.



- P: CW pilots sent, on frame $2(10i+j)$, $i, j=0, \dots, 9$, by ports using (slot i , frequency j) as traffic channel
 - with the same power level as the active traffic channel
- B: Beacons sent, on frames $2m+1, 2m+51, 2m+101, 2m+151$, by port m , where $m=0, \dots, 24$ and it is reused and determined by each port by measurements
 - contains ID and up to 6 unused preferred channels as seen by port
- Both B and P are repeated on slots 0 and 5 of the designated frame
- Portables use reverse beacon slots to request ALTs

Figure 4. Superframe structure on the control frequency.

Continually repeat the procedure and update preferred channel lists every 400 milliseconds



*channel: time-slot/frequency

Figure 5. The DCA algorithm.

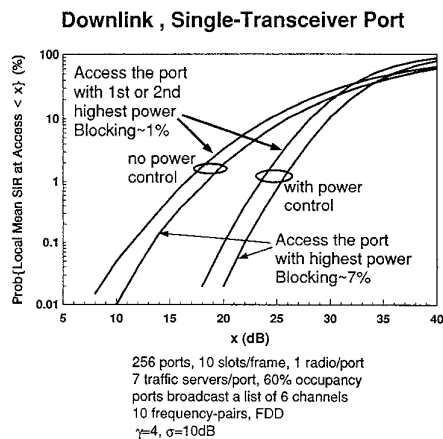


Figure 6. Distributions of downlink local mean SIR at access for the case where each port has only one transceiver.

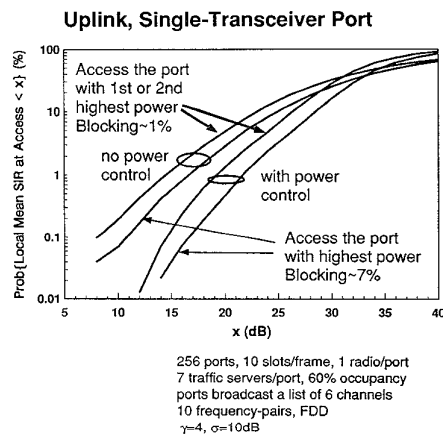


Figure 7. Distributions of uplink local mean SIR at access for the case where each port has only one transceiver.

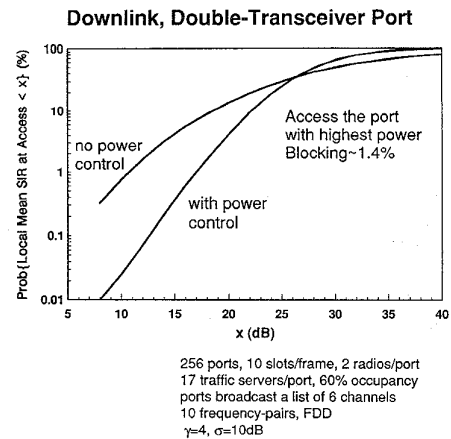


Figure 8. Distributions of downlink local mean SIR at access for the case where each port has two transceivers.

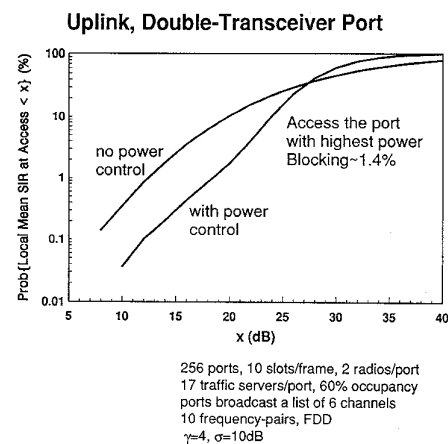


Figure 9. Distributions of uplink local mean SIR at access for the case where each port has two transceivers.