Fixed Wireless Access System with Autonomous Resource Assignment

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ABSTRACT

This paper presents simulation studies of a class of autonomous, Dynamic Channel Assignment [ADCA] protocols applied to a Fixed Wireless Access [FWA] system utilizing TDMA as the multi-access technique. The terms ADCA refers to a call admission/rejection policy where initial time-slot assignment is based only on measurements of the total interference power. The measurement is carried out both by the base-station and the terminal prior to making a time-slot assignment. Once assigned, a time-slot may be replaced if conditions deteriorate. The FWA system uses narrow steerable antenna beams at the base-stations to point at the desired terminal during the assigned time-slot, thereby minimizing the interference generated by transmitters supporting other terminals during the same time-slot. It is shown that with this simple scheme high capacity can be achieved.

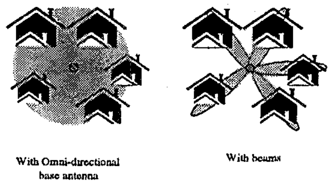
1. INTRODUCTION

Wireless cellular technology has become an increasingly attractive access option for the provision of fixed-line services. In a Fixed Wireless Access (FWA) system, the fixed cellular terminal provides the interface between the public network and the subscriber equipment.

FWA systems differ significantly from mobile systems in their functionality, underlying technology, and propagation environment. As such, the models and methodologies used in the study of mobile systems may not well represent FWA systems. In particular, since the terminals and base stations are fixed, fading due to shadowing and multipath would occur at much slower rate compared to mobile systems.

Among the standards being adapted for FWA systems are, derivatives from cellular such as NMT, TACS, AMPS, GSM/DCS1800, and IS-95, as well as cordless such as DECT, PACS, and CT2. The motive behind this is to make use of infrastructure already available in the cellular arena for FWA applications. Nevertheless, the fixed service requires a different design that takes advantage of the special characteristics of the FWA scenario.

The FWA system proposed in this paper is based on Time Division Multiple Access [TDMA]. The capacity advantage lies in its use of highly directive antennas in contrast to omni directional or wide sector antenna beams, which are used in mobile systems or current FWA systems. The use of directive antennas at the base-stations and the terminals results in large cells sizes and efficient frequency reuse. It can be stated that FWA system move into a new dimension, namely, Spatial Division Multiple Access [SDMA] - through the use of directional antennas, to achieve high capacity. Figure 1 depicts a cell serviced by multiple narrow beam antennas and another served by a single omni-directional antenna. A Base station generates several beams that hop around simultaneously receiving terminal transmission (uplink), and the same number of simultaneously hopping beams for transmission to terminals (downlink). Each beam would communicate with one terminal in a time slot and would hop to another terminal in the next time slot.



With Omni-directional base antenna

With beams

Figure 1: Evolution of Spatial Division Multiple Access.

Our terminal antennas would be typically on roof-tops, high rise buildings, etc. To reduce their size and cost they have lower gain and higher side-lobes than base-station antennas. They are pointing in the direction of maximum signal reception. Base station antennas are mounted on high towers (30-100 ft) at high elevations, if available. They are capable of generating multiple narrow beams simultaneously. Possible applications of the FWA system includes business access, such as PBX backhaul and router interconnections as well as residential voice and internet access.

Our FWA system uses a single segment of frequency spectrum for downlink and another for uplink *i.e.*, Frequency Division Duplexing (FDD) is used. The channel assignment task is then the selection process of a time-slot and an available beam for the downlink and a time-slot, not necessarily the same, and an available beam for the uplink. The suitability of a slot/beam pair for activation of a hitherto idle terminal depends on the interference scenario, which is time variant. The study presented here assumes "channel assignment with autonomous policy", in contrast with alternative protocols, that rely on inter-cell coordination to minimize mutual interference between active links. Specifically, the base-station and the terminal perform measurements of the received interference power on any candidate time-slot, and based solely on these measurements, a decision on the suitability of the time-slot is made. We further elaborate on this topic in section 3. Similar channel assignment protocols have been found efficient for cellular and personal communications systems in previous work [5-7]. In section 2 we discuss the system parameters and simulation models. Resource assignment methodologies are given in section 3. Steps of the simulations and results are presented in sections 4 and 5 respectively.

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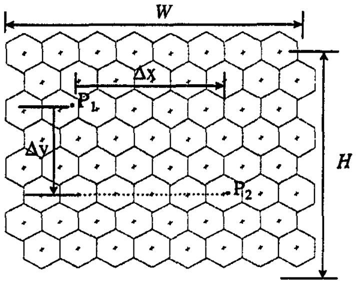
2. FWA SYSTEM SIMULATION MODEL

A. Network Topology

As customary we use hexagonal cellular topology with base stations at the centers of the cells. In order to provide uniform interference picture for all base stations and terminals (in other words to avoid edge effects), an 8x8 cell structure is assumed to be wrapped around on all four sides forming a toroid. Wrap up is achieved by applying the transformation as shown in Figure 2 to the relative coordinates.



wrapping:
If ($\Delta x > W/2$) $\Delta x = \Delta x - W$.
If ($\Delta y > H/2$) $\Delta y = \Delta y - H$.

Figure 2: Base station placement and wrapup rules

B. Terminal Characteristics

Terminals with identical characteristics are uniformly distributed within the service area to give a predefined number of terminals per cell on average. Each terminal is characterized by an ON/OFF activity pattern. The time a terminal stays in idle state is exponentially distributed with mean $1/\lambda$. Similarly, the duration of a connection before hang-up also is exponentially distributed with a different mean $1/\mu$. The activity factor, *AF* of a terminal is defined as the ratio of mean call duration to the sum of mean call duration and mean idling time and hence is expressed as, $AF=\lambda/(\lambda+\mu)$. Note that in the above definition of *AF*, we made the assumption that no external constraints change the activity of the terminals.

Assuming that the only limit is *the number of beams X number of time-slot per frame of the TDMA system, i.e.*, no interference, the blocking probability can be assessed by results from queuing analysis. In particular, this is similar to the *birth-death* process of a pure loss system with finite population, *c* servers, and no storage as discussed in [2]. Thus the blocking probability is given by

$$P_b = \frac{(N-c)P(c)}{\sum_{k=0}^{c}(N-k)P(k)} \qquad (1)$$

where, *N* is the total number of terminals in the cell (active as well as idle), *c is number of beams X number of time-slots per frame* of the TDMA system, and *P(k)* is the steady state probability that *k* channels will be occupied, and is given by the *Engset* distribution as

$$P(k) = \frac{\binom{N}{i}\left(\frac{\lambda}{\mu}\right)^k}{\sum_{i=0}^{c}\binom{N}{i}\left(\frac{\lambda}{\mu}\right)^i} \qquad (2)$$

When the blocking is dominated by the presence of interference, the total number of good channels available to a cell varies with the activity in and around the cell. Let the total number of terminals in the system (active as well as idle) be *n* and *m* of them are active (on call). Since the idling time of a terminal are independent and exponentially distributed, time to an arrival anywhere in the system t_a is exponentially distributed with mean $1/(n-m)\lambda$. Similarly, time for an active terminal anywhere in the system to hang-up (departure) t_d also is exponentially distributed with mean $1/m\mu$. Since the events of an arrival and departure are independent, the joint probability density function that an arrival will happen at t_a and a departure at t_d can be expressed as

$$p(t_a,t_d) = (n-m)m\lambda\mu e^{-(n-m)\lambda t_a} e^{-m\mu t_d} \qquad (3)$$

The probability for the next event to be an arrival is the probability that $t_a<t_d$ which can be evaluated by integrating $p(t_a,t_d)$ in $t_a=0$ to t_d and $t_d=0$ to infinity. The result turns out to be

$$P_a = \frac{(n-m)\lambda}{(n-m)\lambda + m\mu} \qquad (4)$$

The probability for the next event to be a departure simply becomes $1-P_a$. In the simulation, generating a binary random variable, the distribution of which is biased according to these probabilities, makes the choice of next event.

C. Antenna Radiation Patterns

A typical narrow beam antenna pattern is complex with multiple side lobes as shown in Figure 3. An idealized pattern characterized by a main lobe, a side lobe, and a back lobe as shown in Figure 4(b) has been used in the simulations. Terminal antenna radiation patterns are inferior in terms of beam width and side lobe levels compared to that of base stations. Figure 4(a) shows the terminal antenna pattern used in the simulations. These patterns are chosen for computational conveniences.

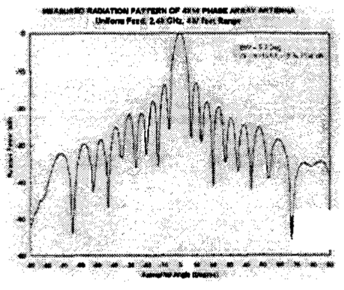


Figure 3: Power radiation pattern of an FWA base antenna

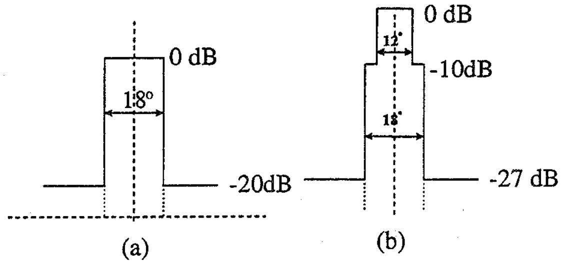


Figure 4: Idealized antenna power radiation patterns (a) terminal (b) base

D. Propagation Environment

The propagation model used in the simulations considers only the long-term behavior of the environment. In particular, the path loss is taken to be a log-normally distributed random variable with a mean, which is a function of the length of the path. The random component is associated with "shadowing" due to obstructions between the transmitter and receiver. The path attenuation can therefore be expressed as ξd^{γ}, where ξ represents the log normal shadow loss. ξ has a zero mean and a standard deviation, σ of 8.0 in the dB scale *i.e.*, $10\log_{10}\xi$ is zero mean gaussian with σ=8.0, d is the distance, and γ is the path-loss exponent. For the base station heights in the range of 30-100ft, the Hata model [8] suggests a value of 3.8 for γ.

We see the random shadowing components of the path losses of links converging on a common terminal to be correlated with a covariance matrix ρ which is a diagonally symmetric square matrix with dimension same as the number of base stations (64 in the simulation) in the entire system. If Ψ is a vector of random numbers representing the shadow fading in dB scale, $E\left[\Psi\Psi^{T}\right] = \rho$ where the superscript T stands for transpose. We have assumed that links arriving at a terminal from "close" directions are highly correlated, while those arriving from significantly different bearings are only moderately correlated. At the same time, we have assumed that links converging onto a base station from different terminals are uncorrelated. The logic behind this is that the random shadow loss component of the path loss is largely determined by shadowing and obstructing objects in close proximity to the terminal antenna, which is some times located in low areas or behind buildings, and typically mounted on roof-tops or walls, while the base station antennas are typically mounted on high towers in open areas. The existence of correlation between path losses of links is mentioned in [1] in a similar scenario when computing the other-cell interference in a cellular CDMA system. For lack of actual field measurements, we chose to model the correlation between the shadow fading components of the path losses of link i and link j converging on a common terminal by the following formula.

$$\rho_{ij} = \begin{cases} \sigma^{2}(0.699 + 0.3\cos\Phi_{ij}), & i \neq j \\ 0, & i = j \end{cases} \qquad (5)$$

where $0<\Phi_{ij}<2\pi$ is the angular separation of the orientations of two links.

3. RESOURCE ASSIGNMENT

The serving base assignment, power settings, and channel assignment/reassignment protocols are discussed in this section.

At the installation phase, the subscriber terminal antennas are fixed so as to point in the direction of maximum received signal thereby locks onto its' serving base. This method would provide significant performance gain compared to selecting the geographically closest base station as the serving base.

Base stations transmit the same power levels for all subscriber terminals *i.e.*, there is no power control on the downlink. We assume a power control scheme for the uplink such that a base station receives the same power level from all subscriber terminals served by that base station regardless of the individual link loss.

Channel assignment is the selection of a time-slot and a beam to support the requesting terminal. The subscriber terminal measures the interference levels on downlink in all time-slots and lists the slots in ascending order of interference. The terminal then sends the list of time-slots along with the interference levels to the serving base station. The serving base station records the information and selects the least interfered time-slot if it can provide the necessary Signal-to-Interference Ratio (SIR) and if there is an unoccupied beam available. In our simulations the required SIR target was set at 17 dB. If such a time-slot cannot be found the call request is blocked. Having successfully selected a downlink time-slot, the base station measures the SIR levels on the uplink in all time-slots and lists in ascending order of interference. A time-slot/beam combination is selected in the same manner as for the downlink. The call is blocked on the unavailability of a suitable time-slot/beam combination.

A new channel assignment as described above would cause interference to terminals already active. As there is no pre evaluation of such interference, the SIR levels of some of these terminals may decrease below the required threshold. In such situations the call may be reassigned to an alternative time-slot or dropped if no good assignment is possible. If there is a requirement for a reassignment it is carried out through the same procedure as the initial assignment. A call will be dropped if there were no time-slots available with minimum required level of SIR for reassignment. Otherwise the call may be reassigned as many times as necessary until it departs naturally. These reassignments in turn may initiate further reassignments. In this continued process, a time-slot may be chosen second time for the same terminal for the same call restarting a "loop" of slot assignments leading to oscillatory behavior. Such oscillations may cause excessive amount of control operations under heavy traffic conditions. In our model we prevent situations like this by disallowing a call to use the same time-slot more than once.

4. SIMULATION FLOW

The equipment setting for the simulation are 8 beams per base station and 10 time slots/frame. The choice of number of beams gives us performance in the vicinity of interference limit for the given beam characteristics.

An iteration of the simulation comprises an initialization phase followed by a "dynamic" phase. The System initialization in an iteration of the simulation consists of the following steps.

1. Generate coordinates for terminals, uniformly distributed within the service area. The x and y coordinates are independently chosen from a uniform distribution. The average number of terminals per cell is set to be 600.
2. For each terminal, compute the relative coordinates for base stations with respect to the terminal with the assumption of "wrap-up". Compute the distance to each base station and hence the distance dependent path losses. Compute the 64 x 64 matrix of angular separation, $\mathbf{\Phi}$.
3. Form the 64 x 64 matrix of correlation coefficients, ρ by using the expression in equaiton (5) on the elements of $\mathbf{\Phi}$.
4. For each terminal, generate a vector, Ψ of 64 correlated gaussian random numbers using the following procedure. Find the "matrix square root", $\mathbf{L}$ of ρ such that $\rho=\mathbf{L}\mathbf{L}^T$. Generate Ψ using the transformation $\Psi=\mathbf{L}\Gamma$ on a vector of independent gaussian random numbers Γ with zero mean and standard deviation, σ=8.0dB. The log normal random numbers are obtained by the transformation $10^{\Psi/10}$.
5. Compute the total path losses resulting from distance and shadow fading. Store values.

In the dynamic simulation phase the propagation environment and the network parameters are fixed to the above calculated values. The system starts with no active terminals, hence the first event is an arrival. As the terminals are transferred from the "idle" pool to the "active" pool (through the time-slot/beam assignment protocol) the departure probability starts to increase from its initial value of zero. At a certain point "flow balance" is achieved when the arrival rate is equal to the sum of departure, blocking, and dropping rates. Neglecting the dropping rate,

$$\lambda(n-m) = \lambda(n-m)P_b + \mu m \qquad (6)$$

where P_b is given by equation 1. This equation can be solved for m which is an estimate of the number of active terminals at the "steady state". Data collection for analysis starts when there are m active terminals for the first time. Simulation is continued untill a sufficient statistics is collected.

5. PERFORMANCE

The performance is assessed through evaluation of probabilities of call blocking, call dropping, and unsuccessful calls (Figure 5-7). The probability of unsuccessful call in this context is defined as the sum of call blocking and dropping probabilities. These metrics are presented against activity factor which is a measure of terminal characteristics. The activity factor given here is that of a terminal activity pattern when there is no call blocking or dropping. Note that due to the call blocking phenomenon, the distribution of idle time duration is modified. Similarly, the call dropping phenomenon modifies the distribution of call duration. The terminals being blocked and dropped are immediately taken back to the idling pool of terminals, which are potential call generators thus increasing the overall call initiation rate.

The curve shown as "Engset Blocking" in Figure 5 gives the blocking probability given by equation 1. Note, there is no call dropping associated with this case. The blocking performance of least interfered time-slot assignment with a threshold of 17dB and **no reassignment** is found to result in blocking performance better than that of Engset Blocking for activity factors larger than 0.0965. This is due to the fact that there is a significant call dropping probability leading to less number of active calls in the system. In this case 10% of the admitted calls are found to prematurely dropped for an activity factor of 0.1. In the combined call blocking and dropping performance, given in Figure 7, the performance as computed from Engset blocking formula is given as "Engset Bound". It is seen that the performance of time-slot assignment with no reassignment is significantly above the "Engset Bound".

The simulation results show that the high level of dropping probability can be reduced by reassigning the time slots of those terminals for which the SIR levels drop below the required threshold of 17dB. The call blocking probability for this strategy is twice as much as that without reassignment. Nevertheless there is a ten-fold gain in the call dropping probability (0.01 versus 0.1 at an activity factor of 0.105). At a blocking probability of 1%, the activity factor is 0.1035. The dropping rate at this activity factor is found to be around 0.8%.

Figure 8 shows statistics of the number of reassignment experienced by an ongoing call at an activity factor of 0.095. The histogram shows that more than 86% of the admitted calls do not experience any channel reassignments within the conversational period. Only less than 0.5% of the admitted calls undergo more than 2 reassignments.

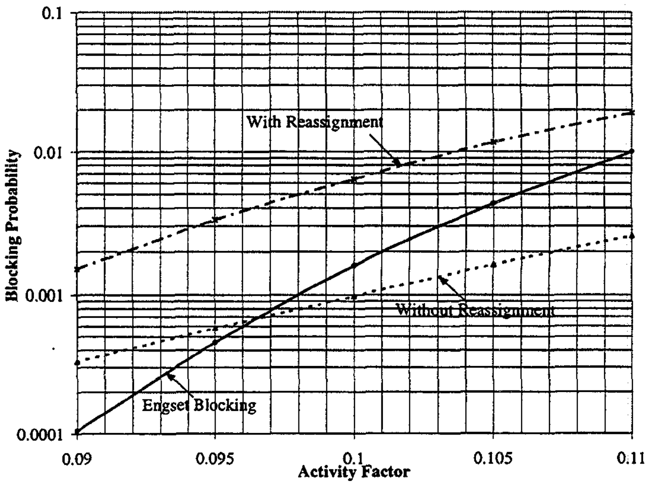


Figure 5: Blocking performance

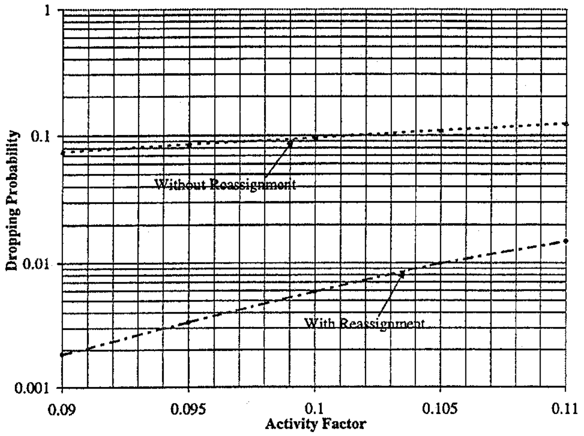


Figure 6: Call Dropping performance.

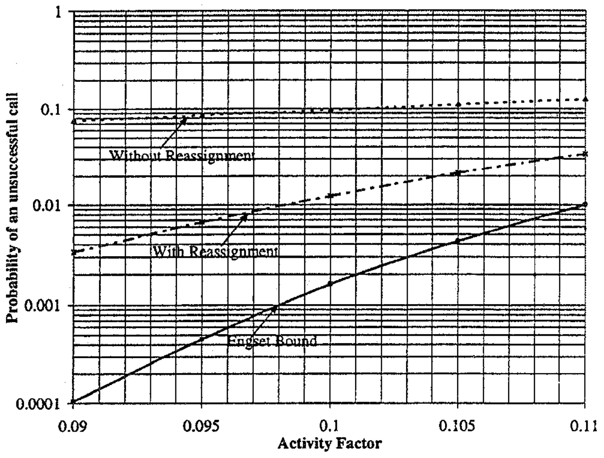


Figure 7: Overall Performance - Probability of a call being blocked at the intial assignment or being dropped due to forced termination

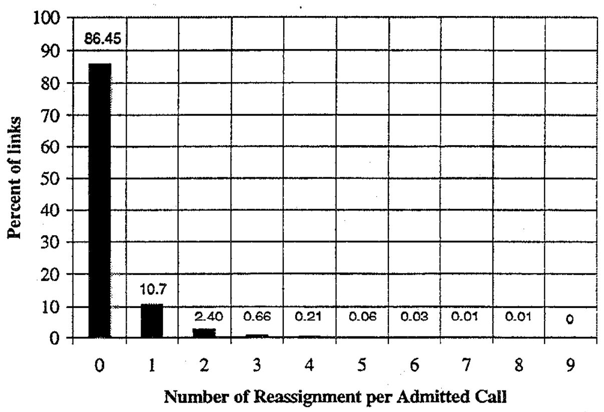


Figure 8: Percentage of links undergoing channel reassignments versus the number of reassignments per link at AF=0.095.

4. SUMMARY AND CONCLUSIONS

Performances of autonomous channel assignment protocols on proposed Advanced Wireless Access System were studied via simulation. The simulation results reveal that channel assignment with autonomous policy would be an excellent choice for FWA system. However, channel reassignment will be essential to maintain the required performance level. Such channel reassignment methodology should ensure that there is no possibilities for oscillatory behavior leading to excessive control operations. We presented one channel reassignment scheme that can guarantee a stable behavior of the system and showed through simulations that this channel assignment/reassignment method has good blocking and call dropping performance.

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