

# On the Mobility/Capacity Conversion in Wireless Networks

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**Abstract**— We show in the paper that mobility and capacity can be viewed as equals, and develop an analytical model to study the conversion process between the two. The goal of the study is to design a network with a free convertibility between mobility and capacity. Such a network can support more users because whenever user mobility drops, it can convert that change into a capacity gain.

## I. INTRODUCTION

Conventionally, the Quality of Service (QoS) is determined by the call blocking probability  $P_{NB}$  and the call dropping probability  $P_D$  (the probability that a call is terminated before the connection ends). For a given requirement of  $P_{NB}$  and  $P_D$ , the capacity  $C$  of a cellular network is described by (1),

$$C(P_{NB}^*, P_D^*) = \frac{Er(R, P_{NB}^*, P_D^*)}{\alpha R^2} \quad (1)$$

where  $Er(R, P_{NB}^*, P_D^*)$  is the traffic (in Erlang) carried by a cell,  $R$  is the diameter of the cell,  $\alpha$  is a normalized constant for the cluster size, and  $P_{NB}^*$  and  $P_D^*$  are the required values for  $P_{NB}$  and  $P_D$ . Although mobility is not explicit in (1), its impact on network capacity is obvious. As mobility increases, a call will experience more handoffs during its lifetime. To maintain the same QoS, the system must increase the probability of a successful handoff. It can be done by lowering the input load to make channels more available for handoffs. The result is a smaller Erlang for each channel. If we plot capacity against mobility (the mathematical definition of mobility is given in section III), we will get a curve in Fig. 1.

From Fig. 1, we can see that given a fixed QoS constraint, a wireless network has to sacrifice its capacity to support a higher degree of mobility. We can evaluate a network from its mobility/capacity conversion process. As an example, the two networks in Fig. 1 have the same capacity for stationary users, but network B has a more efficient mobility/capacity conversion process, and thus a higher capacity as user mobility increases.

Understanding the mobility/capacity conversion process can offer new insights into the design of a wireless network. This is the motivation behind our study. Two trends have increased the relevance of the study. One is mini cells. Reducing  $R$ , as indicated in (1), will increase the capacity. But it also

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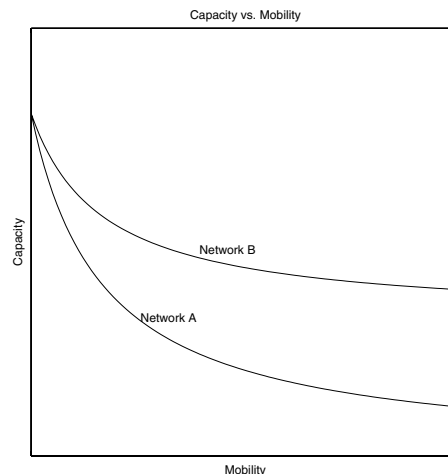


Fig. 1. A comparison of the mobility/capacity conversion processes of two networks.

increases the number of handoffs, and has the same effect as increasing mobility and reducing capacity. The real capacity gain should consider the joint effects of the two. Past studies have often ignored this interaction. The second trend is multimedia applications. Some connections may carry a bandwidth many times that of a voice connection. If hand over one voice channel is problematic, imagine the architecture implication of handing over a channel ten times that rate. The subject of mobility/capacity conversion applies to all wireless networks. As a starting point, we analyze the mobility/capacity conversion in a conventional TDMA/FDMA network.

## II. MOBILITY STRATEGIES IN VARIOUS NETWORKS

We analyze the mobility/capacity conversion processes of three types of networks. Each represents a different strategy for handling mobility. A fixed channel assignment (FCA) network divides the total number of channels  $N$  among a cluster of cells. A 4-cell cluster network is shown in Fig. 2. Channel reservation [1] [2] has been proposed to reduce call dropping probabilities. Its effectiveness will be studied later in section III.

A DCA network can allocate all its channels to one cell. It will increase the radio equipment cost. Recent proposals of fiber-optic radio systems can considerably reduce that cost

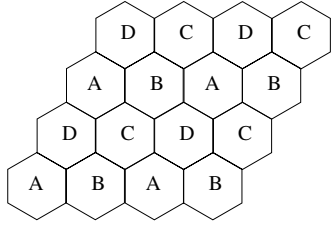


Fig. 2. 4-cell cluster in hexagonal system.

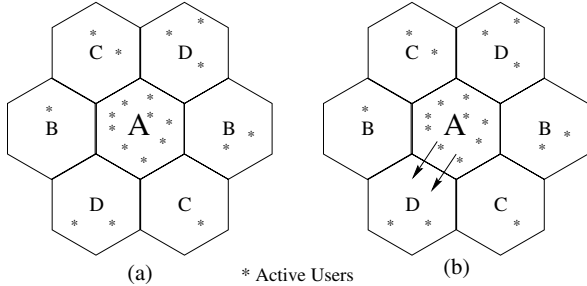


Fig. 3. An example of mobility handling in a DCA network: (a) DCA will allocate many channels to cell A; (b) Users moving out of cell A are likely to be dropped because most channels are already allocated to cell A.

[3] [4]. DCA can improve trunking efficiency (thus blocking probability), but not necessarily the call dropping probability. Consider the example in Fig. 3 where users are unevenly located inside the network. With DCA, the system can allocate more channels to cell A and serve more users that are otherwise blocked in an FCA network. However, if users move out of cell A, many will be dropped because most channels are already allocated to cell A.

A MAWCC (stands for MAcro-diversity Without Channel Confinement) network [5] goes one step further by allowing a user to carry the assigned channel to a new cell (non-channel-confinement). Its network capacity can flow with user movement and the call dropping problem in Fig. 3 can be prevented. Non-channel-confinement obviously requires DCA, but DCA alone is not enough. The radio quality of a channel varies drastically from cell to cell. With macro-diversity, we can select another surrounding base station to serve the channel when radio quality is bad. This greatly enhances the feasibility of the channel-carrying feature. Macro-diversity implementation in MAWCC is based on a conventional three-sector antenna system (Fig. 4a). It can be seen that the area surrounded by the dashed lines are also hexagons (Fig. 4b). If we consider the dashed lines as the cell boundary, the three antennas will sit on the three corners of the cell. This is the structure of a macro-diversity cell in MAWCC [6].

### III. ANALYTICAL MODEL FOR MOBILITY/CAPACITY CONVERSION

Although an analytical model can not capture all implementation details, it does offer important insights into the mobility/capacity conversion process. Many analysis of wireless networks are based on a single-cell model [7] [8] in which the

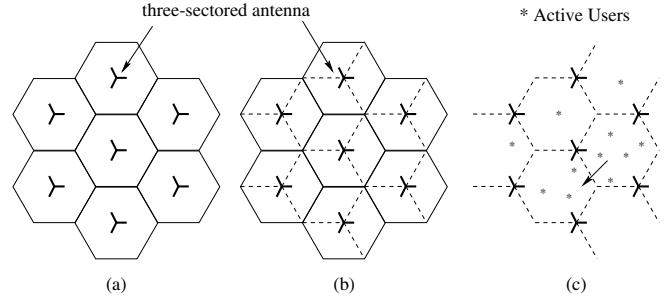


Fig. 4. MAWCC architecture: (a) A conventional three-sector antenna system; (b) If we consider the areas surrounded by dashed lines as cells, then each cell has three antennas sitting on the three corners; (c) In MAWCC, users could carry their own channels when they move from cell to cell.

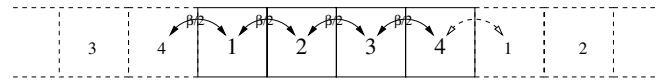


Fig. 5. The wrapping-around 4-cell system model.

handoff arrival rate is derived through iteration [9]. This single-cell approximation, however, is not useful for our problem because it can not model the inter-cell dependency, which is required for analyzing the mobility/capacity conversion process.

In the following we develop a multi-cell analytical model for a linear array of  $M$  cells wrapping around. A linear model has been used in literature before [10] [11]. Our model has the following characteristics:

1. The system is a linear array of  $M$  cells wrapping around (Fig. 5). We assume  $M = 4$  in our study.
  2. The channel reuse distance is 2. That is, when a channel is used in a given cell, it can not be used in its neighboring cells.
  3. In a tiny interval  $\Delta t$ , a mobile user will move to its neighboring cell, left or right, with a probability of  $(\beta/2)\Delta t$ . Thus a user will stay in the same cell with the probability  $(1 - \beta\Delta t)$ .
  4. New calls are generated in each cell based on Poisson arrivals with rate  $\lambda$ . The connection time has a negative exponentially distributed function with the mean  $1/\mu$ .
- The mobility of the system is determined by  $\gamma$ , the average number of handoffs during the lifetime of a call.

$$\gamma = \frac{\beta}{\mu} \quad (2)$$

In the rest of the paper, we will study how the network capacity is affected by mobility under the given QoS constraint:  $P_{NB}^* = 0.05$  and  $P_D^* = 0.01$ . Without loss of generality, we assume  $\mu = 1$  in the figures. We also assume that the traffic is evenly distributed among all cells.

#### A. FCA Networks

An FCA network [12] [13] divides the total number of channels among a cluster of cells. In the linear model, the cluster size is 2 (i.e., channel reuse constraint is 2). Once a channel is used in a cell, it cannot be used in its neighboring

cells. Our state variable is  $\mathbf{m} = [n_1, n_2, n_3, n_4]$ , where  $n_i|_{i=1,2,3,4}$  represents the number of active mobile users in cell  $i$ , ( $0 \leq n_i \leq \frac{N}{2}$ ). In total, there are  $(\frac{N}{2} + 1)^4$  states. To facilitate the analysis, we first convert the 4-dimensional Markov process to a one-dimensional one by re-numbering the states. The mapping from  $\mathbf{m} = [n_1, n_2, n_3, n_4]$  to one integer  $s(\mathbf{m})$  is given in (3), where  $N_c = \frac{N}{2}$  is the number of channels per cell.

$$s(\mathbf{m}) = \sum_{i=1}^4 n_i (N_c + 1)^{(i-1)}, \quad (3)$$

$$s \in \{0, 1, 2, \dots, (N_c + 1)^4 - 1\}$$

For FCA, it is straight forward to generate the probability transition rate matrix  $\mathbf{A} = [a_{xy}]$ . Given  $\mathbf{A}$ , we can compute the *Steady State Probability*  $\mathbf{P} = [\mathbf{P}(0), \mathbf{P}(1), \mathbf{P}(2), \dots, \mathbf{P}(N_s)]_{N_s=(N_c+1)^4-1}$ . Let  $\mathbf{P}_{NB}(\mathbf{m})$  and  $\mathbf{P}_{HB}(\mathbf{m})$  represent the new call blocking probability and the handoff blocking probability when the system is in state  $\mathbf{m}$ . Then they can be formulated as in (4) and (5) under an evenly distributed traffic assumption, where  $i_{Left}$  and  $i_{Right}$  represent the left and the right cell (wrapped around) of the  $i_{th}$  cell respectively.

$$\mathbf{P}_{NB}(\mathbf{m}) = \frac{\sum_{i=1}^4 \Delta(n_i)}{4} \quad (4)$$

$$\mathbf{P}_{HB}(\mathbf{m}) = \sum_{i=1}^4 \frac{(n_{i_{Left}} + n_{i_{Right}}) \times \Delta(n_i)}{2} \quad (5)$$

$$\Delta(n_i) = \begin{cases} 0, & \text{if } n_i < N_c \\ 1, & \text{if } n_i = N_c \end{cases} \quad (6)$$

$$i_{Left} = (i - 2) \bmod M + 1 \quad (7)$$

$$i_{Right} = i \bmod M + 1 \quad (8)$$

The *New Call Blocking Probability*  $P_{NB}$  and *Handoff Blocking Probability*  $P_{HB}$  of the system can be calculated by equations (9) and (10).

$$P_{NB} = \mathbf{P}(\mathbf{m}) \cdot \mathbf{P}_{NB}(\mathbf{m}) \quad (9)$$

$$P_{HB} = \mathbf{P}(\mathbf{m}) \cdot \mathbf{P}_{HB}(\mathbf{m}) \quad (10)$$

Let  $P_H$  be the probability that an active mobile user needs a handoff before its connection is completed. Since the connection time and cell dwell time are all negative-exponentially-distributed random variables, we have

$$P_H = \frac{\beta}{\beta + \mu}. \quad (11)$$

Let  $P_k$  be the probability that a connection is dropped in its  $k_{th}$  handoff, then

$$P_k = P_H P_{HB} [P_H (1 - P_{HB})]^{k-1}. \quad (12)$$

We can derive the call dropping probability  $P_D$  as

$$\begin{aligned} P_D &= \sum_{k=1}^{\infty} P_k \\ &= \sum_{k=1}^{\infty} P_H P_{HB} [P_H (1 - P_{HB})]^{k-1} \\ &= P_H P_{HB} \sum_{k=0}^{\infty} [P_H (1 - P_{HB})]^k \\ &= \frac{P_H P_{HB}}{1 - P_H (1 - P_{HB})} \\ &= \frac{\frac{\beta}{\beta + \mu} P_{HB}}{1 - \frac{\beta}{\beta + \mu} (1 - P_{HB})}. \end{aligned} \quad (13)$$

Substituting  $\frac{\beta}{\mu}$  by  $\gamma$ , we have

$$P_D = \frac{\gamma \times P_{HB}}{1 + \gamma \times P_{HB}}. \quad (14)$$

Channel dropping is more annoying to customers than call blocking, and channel reservation has been proposed to reduce call dropping probability [1] [2]. A simple reservation scheme is to reserve  $N_{cr}$  channels per cell for handoffs. That is, when the number of users in cell  $i$  is in the range

$$(N_c - N_{cr}) \leq n_i < N_c, \quad (15)$$

new connections are blocked and only handoff connections are accepted. We also study a partial reservation scheme where a new call in cell  $i$  can be accepted with a probability of  $q(n_i)$  when the system is in state  $\mathbf{m} = [n_1, n_2, n_3, n_4]$ . An example of the scheme is given in (16).

$$q(n_i) = \begin{cases} 1, & \text{if } n_i < N_c - 2 \\ 1 - b_2, & \text{if } n_i = N_c - 2 \\ 1 - b_1, & \text{if } n_i = N_c - 1 \end{cases} \quad (16)$$

## B. DCA Networks

Various DCA strategies have been proposed [14] [12] [15] [13]. The DCA scheme studied below assume that all channels can be allocated to one cell, provided that the channel reuse constraint is satisfied. When a user completes his/her call, the channel is returned to the central pool. Different DCA schemes also differ in channel selection. We study two channel selection schemes below.

1) *Random Packing*: Channels are numbered from 1 to  $N$ . When a channel is required (for a new call, or a handoff call), the system searches the channel list from top to bottom and uses the first available one that satisfies the reuse constraint.

2) *Compact Packing*: The system chooses a channel which is already used in another cell (provided that it meets the channel reuse distance constraint). A new channel will be used only if none of the existing channels can meet the reuse distance constraint. When multiple feasible channels are available, the search procedure is the same as in 1).

The reuse constraint in our system is 2. If a channel is used in cell  $i$ , it can only be reused in cell  $i_{Reuse}$ , where

$$i_{Reuse} = (i \bmod 4 + 1) \bmod 4 + 1 \quad (17)$$

TABLE I

CHANNEL UTILIZATION VECTOR  $\mathbf{u}(ch)$  AND CORRESPONDING CHANNEL STATE INDEX NUMBER  $s(ch)$ 

$s(ch)$	0	1	2	3	4	5	6
$\mathbf{u}(ch)$	[0000]	[0001]	[0010]	[0100]	[1000]	[0101]	[1010]

In the 4-cell cluster model under study, each channel has 7 possible allocation patterns as shown in Table I. Each pattern is called a *Utilization Vector* (UT) of that channel. Let  $\mathbf{u}(i)$  represent the UT of channel  $i$ . We then construct a Markov process with state variable  $\mathbf{m} = [\mathbf{u}(1), \mathbf{u}(2), \dots, \mathbf{u}(N)]^T$ , where  $N$  is the total number of channels of the system. We can also view  $\mathbf{m}$  as a matrix in which each row corresponds to a channel and each column corresponds to a cell. For example, assume the total number of channels  $N = 4$  and  $\mathbf{u}(1) = [0001]$ ,  $\mathbf{u}(2) = [1010]$ ,  $\mathbf{u}(3) = [0100]$ ,  $\mathbf{u}(4) = [1010]$ . Then we have the state variable  $\mathbf{m}$  shown in (18). From the 4<sub>th</sub> row, we find that channel 4 is used in two different cells; from column 3, we see that cell 3 has two active mobile users.

$$\mathbf{m} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \end{bmatrix} \quad (18)$$

There are  $7^N - 1$  states in total in the model. Although this approach generates a large number of states, it offers unprecedented flexibility that make possible the analysis of different DCA schemes.

As in FCA, we first re-number the states and make the process one dimensional by mapping  $\mathbf{m}$  an integer  $S(\mathbf{m})$  according to (19), where  $s(ch)$  is drawn from Table I.

$$S(\mathbf{m}) = \sum_{ch=1}^N s(ch) \times 7^{(ch-1)}, \quad (19)$$

$$S \in \{0, 1, 2, \dots, N_S\}_{N_S=7^N-1}$$

Generating the probability transition rate matrix  $\mathbf{A}$  is not a trivial matter for a DCA network. One example of state transitions between states is shown in Fig. 6. We have to write a program to generate  $\mathbf{A}$  for both DCA schemes. Once the transition rate matrix  $\mathbf{A}$  is obtained, we can compute the *Steady State Probability*  $\mathbf{P} = [\mathbf{P}(0), \mathbf{P}(1), \mathbf{P}(2), \dots, \mathbf{P}(N_s)]$ .

When the system is in state  $\mathbf{m}$ , the new call blocking probability  $\mathbf{P}_{NB}(\mathbf{m})$  is given in (20), where the term  $1/4$  comes from the fact that a new call can be generated in any of the four cells with equal probability.

$$\mathbf{P}_{NB}(\mathbf{m}) = \frac{\sum_{i=1}^4 \Delta_i(\mathbf{m})}{4} \quad (20)$$

$$\Delta_i(\mathbf{m}) = \begin{cases} 1, & \text{if a new call is blocked, given that} \\ & \text{the new call is generated in cell } i \\ & \text{and the system is in state } \mathbf{m}; \\ 0, & \text{otherwise} \end{cases} \quad (21)$$

For example if  $\mathbf{m} = [0001, 1010, 0100, 1010]^T$ , then  $\Delta_3(\mathbf{m}) = 1$  because a new call in cell 3 finds no channel available, but  $\Delta_2(\mathbf{m}) = 0$  since channel 1 can still be used

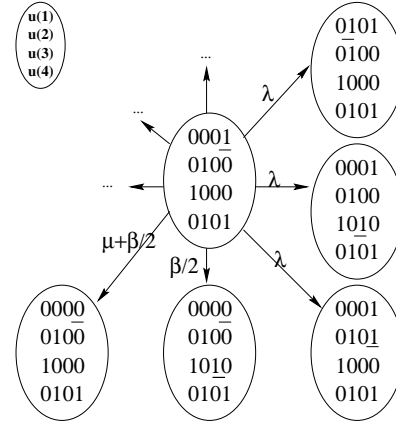


Fig. 6. An example of state transitions in DCA (for both packing schemes) with 4 channels, where  $\mathbf{u}(i)_{i=1,2,3,4}$  represents the Utilization Vector of channel  $i$ . The changed elements in state transitions are underlined.

if the new call arrives in cell 2. Our program also generates  $\Delta_i(\mathbf{m})$  and  $\mathbf{P}_{NB}(\mathbf{m})$  for all states.

Let  $\mathbf{m}(k, i)$  in (22) denote the element of the  $k$ <sub>th</sub> row and  $i$ <sub>th</sub> column in matrix  $\mathbf{m}$  (see (18)). Then  $\mathbf{m}(k, i)$  is 1 if channel  $k$  is used in cell  $i$ , otherwise 0.  $\mathbf{P}_{HB}(\mathbf{m})$  can be written as (22), where the denominator represents the total number of users in state  $\mathbf{m}$  and the numerator represents sum of blocking probability for each user if he/she moves (note that moving to the left and to the right have the same probability).  $\epsilon_{i_{Right}}(\mathbf{m}(k, i))$  can be defined the same way as  $\epsilon_{i_{Left}}(\mathbf{m}(k, i))$ .

$$\mathbf{P}_{HB}(\mathbf{m}) = \frac{\sum_{i=1}^4 \sum_{k=1}^N \frac{\epsilon_{i_{Left}}(\mathbf{m}(k, i)) + \epsilon_{i_{Right}}(\mathbf{m}(k, i))}{2}}{\sum_{i=1}^4 \sum_{k=1}^N \mathbf{m}(k, i)} \quad (22)$$

$$\epsilon_{i_{Left}}(\mathbf{m}(k, i)) = \begin{cases} 1, & \text{if the handoff is blocked when} \\ & \text{the user } \mathbf{m}(k, i) \text{ moves to the} \\ & \text{left cell;} \\ 0, & \text{otherwise} \end{cases} \quad (23)$$

Let's use the same example  $\mathbf{m} = [0001, 1010, 0100, 1010]^T$ . Then  $\mathbf{m}(3, 2)$  is a user in cell 2 with the assigned channel = 3. When the user moves right into cell 3, none of the channels 1, 2, and 4 can be allocated to the user (allocating 1 will violate the reuse constraint of the channels, and channel 2 and 4 are already used in cell 3). Thus  $\epsilon_{i_{Right}}(\mathbf{m}(3, 2)) = 1$ .

Finally, given  $\mathbf{P}_{NB}(\mathbf{x})$  and  $\mathbf{P}_{HB}(\mathbf{x})$ , we can compute  $P_{NB}$  and  $P_D$  in the same way as in (9) and (10).

### C. MAWCC Networks

In the analysis of a MAWCC network, we ignore the macro-diversity gain and still use reuse distance = 2. Thus the model concentrates on non-channel-confinement characteristic of MAWCC. Handoffs may not be necessary in MAWCC when users cross cell boundaries. To capture this effect, we introduce the concept of "virtual handoff". A *virtual handoff* will happen whenever a user cross cell boundaries, but it will be a success if no "real" handoff is needed (i.e., the same

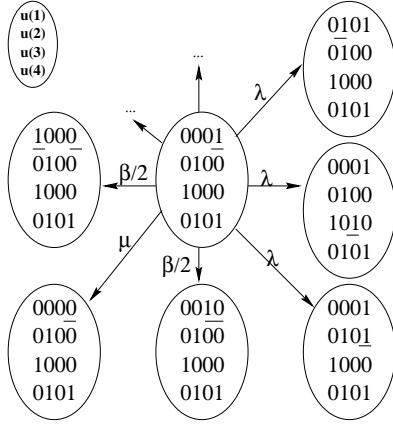


Fig. 7. An example of state transitions in MAWCC (for both packing schemes) with 4 channels, where  $\mathbf{u}(i)_{i=1,2,3,4}$  represents the Utilization Vector of channel  $i$ . The changed elements in state transitions are underlined.

channel can be carried into a new cell). The probability of a success for a *virtual handoff* will be much higher than a successful handoff in a DCA network.

The state variable is the same as in a DCA network:  $\mathbf{m} = [\mathbf{u}(1), \mathbf{u}(2), \dots, \mathbf{u}(N)]$ , where  $\mathbf{u}(i)$  is the UT of channel  $i$ . Fig. 7 illustrates the difference between MAWCC and DCA for the same example given in Fig. 6. Again we need to write a program to generate  $\mathbf{A}$ . Due to space limitation, the program is not shown.

For a given state  $\mathbf{m}$ , the derivation for  $\mathbf{P}_{NB}(\mathbf{m})$  is similar to that in (20) and the *Virtual Handoff Blocking Probability*  $\mathbf{P}_{VHB}(\mathbf{m})$  can be formulated as (24).

$$\mathbf{P}_{VHB}(\mathbf{m}) = \frac{\sum_{i=1}^4 \sum_{k=1}^N \frac{\tilde{\epsilon}_{i_{Left}}(\mathbf{m}(k,i)) + \tilde{\epsilon}_{i_{Right}}(\mathbf{m}(k,i))}{2}}{\sum_{i=1}^4 \sum_{k=1}^N \mathbf{m}(k,i)} \quad (24)$$

$$\tilde{\epsilon}_{i_{Left}}(\mathbf{m}(k,i)) = \begin{cases} 1, & \text{if the virtual handoff is blocked} \\ & \text{when the user } \mathbf{m}(k,i) \text{ moves to} \\ & \text{the left cell;} \\ 0, & \text{otherwise} \end{cases} \quad (25)$$

The *New Call Blocking Probability*  $P_{NB}$  and *Virtual Handoff Blocking Probability*  $P_{VHB}$  of the system can be calculated from (9) and (26).

$$P_{VHB} = \mathbf{P}(\mathbf{m}) \cdot \mathbf{P}_{VHB}(\mathbf{m}) \quad (26)$$

Similar to (12), we can compute  $P_k$  (the probability that a connection is dropped in its  $k_{th}$  virtual handoff) as

$$P_k = P_{VH} P_{VHB} [P_{VH}(1 - P_{VHB})]^{k-1}, \quad (27)$$

where  $P_{VH} = (\beta/(\beta + \mu))$  is the probability that an active mobile needs a virtual handoff (i.e., moving out of the current cell) before the connection is completed. Then similar to (14),

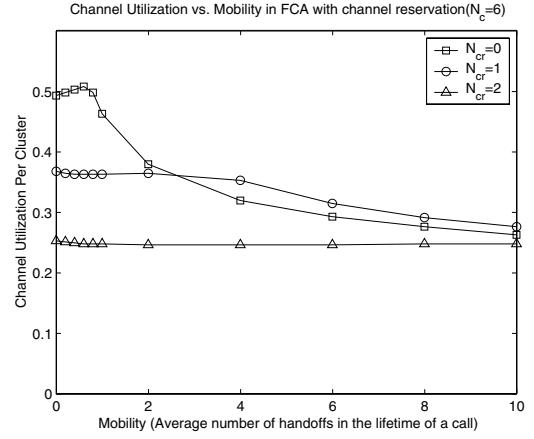


Fig. 8. Channel Utilization vs. mobility in FCA scheme:  $N_c = 6$  ( $N = 12$ ),  $N_{cr} = 0, 1$  and  $2$  respectively, in which  $N_{cr} = 0$  is the simple FCA scheme. Assume  $\mu = 1$  and given QoS constraint:  $P_{NB}^* = 0.05$  and  $P_D^* = 0.01$ .

the call dropping probability  $P_D$  would be formulated as

$$\begin{aligned} P_D &= \sum_{k=1}^{\infty} P_k \\ &= \sum_{k=1}^{\infty} P_{VH} P_{VHB} [P_{VH}(1 - P_{VHB})]^{k-1} \\ &= \frac{\gamma \times P_{VHB}}{1 + \gamma \times P_{VHB}}. \end{aligned} \quad (28)$$

#### D. Results

Fig. 8 shows the channel utilization (per cluster) of an FCA network under different mobility conditions  $\gamma (= \beta/\mu)$  for  $N = 12$  ( $N_c = 6$ ) and  $N_{cr} = 0, 1, 2$ . As expected, the system capacity drops as user mobility increases. Channel reservation can improve the system performance when the mobility is high, but will degrade the performance when the mobility is low. This is consistent with intuition: reserving channels for handoffs is a waste when users are not moving much. Unless we can predict the mobility correctly, the effectiveness of channel reservation for combating mobility is not clear. The same can be said about a partial reservation scheme (not shown, due to space limitation).

Due to a large number of states, we only present the results for  $N = 4$  for DCA and MAWCC networks (Fig. 10). We later describe simulation results for networks with a large number of channels. When mobility is 0, as expected, both MAWCC and DCA have a higher capacity due to its trunking efficiency. However, as mobility increases, a MAWCC network will have a higher capacity than a DCA network because of its non-channel-confinement property. From the figure we also see that channel reservation is not an efficient tool for handling mobility for DCA either.

#### IV. NETWORKS WITH A LARGE NUMBER OF CHANNELS

The DCA and MAWCC network presented are for networks with a small number of channels. For networks with a large number of channels, we use simulation to explore

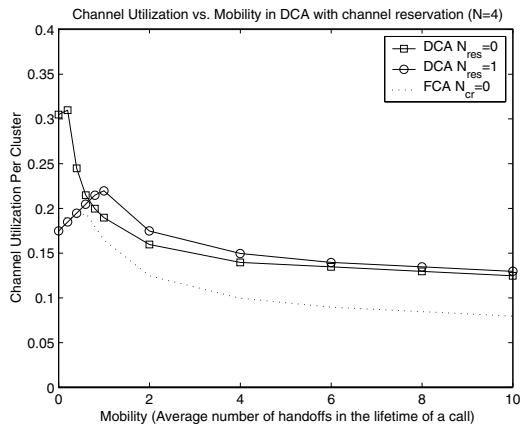


Fig. 9. Channel Utilization vs. mobility in DCA scheme with totally  $N_{res}$  out of  $N$  channels reserved for handoffs:  $N = 4$ ,  $N_{res} = 0$  and 1 respectively. Assume  $\mu = 1$  and given QoS constraint:  $P_{NB}^* = 0.05$  and  $P_D^* = 0.01$ .

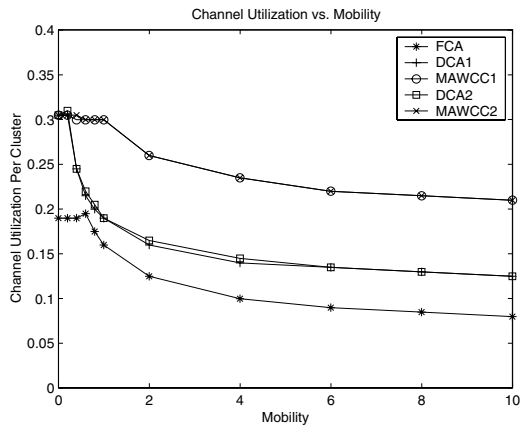


Fig. 10. A comparison of Channel Utilization of FCA, DCA and MAWCC schemes under different mobility condition. Total number of channels  $N = 4$ . DCA1 and MAWCC1: Random Packing; DCA2 and MAWCC2: Compact Packing. Assume  $\mu = 1$  and given QoS constraint:  $P_{NB}^* = 0.05$  and  $P_D^* = 0.01$ .

the mobility/capacity conversion process. We simulate a 60-channel, two-dimensional network. Layer processing (base station, switching office, etc) for a handoff request is modelled as one queue. A handoff is dropped if it cannot be processed in two seconds. Due to space limitation, we only summarize the results below.

1. First we study the condition where the handoff processing time is zero. Capacity will drop in all three networks, as in section III. But MAWCC and DCA will have a similar performance (better than FCA). Which means that trunking efficiency will dominate the performance, not the channel-carrying feature.

2. We then simulate the case with the average handoff processing time = 200ms. In this case, MAWCC (channel carrying) will outperform the other two in the same way as the results showed in section III. If a handoff is not processed in time, it will be dropped, so the penalty for handoffs is higher. Channel carrying will be a useful tool for handling mobility.

## V. CONCLUSION

We have explored the mobility/capacity conversion process in conventional wireless networks. The results will be extended to CDMA and multimedia networks. In addition to analytical models developed for mobility/capacity conversion, our results lead to a more practical implication: mobility and capacity can be treated as equals. A wireless network, if designed correctly, should have a free convertibility between them. Current wireless networks do not have this capability. Consequently, when user mobility decreases, current networks can not take advantage of the mobility change and convert it into a capacity gain and support more users. Future wireless networks can benefit from the free convertibility concept.

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