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A Distributed Dynamic Channel Assignment Algorithm in Highway Microcells

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Abstract

A distributed dynamic channel assignment algorithm is proposed and its performance is examined in a highway microcellular radio environment. In the two-step ordered local packing (TOLP) scheme, channels are assigned on an ordered basis under cochannel interference constraints. One-step and two-step reassignment are used to increase the channel utilization in congested microcell region. A selection criterion is employed to decide the cell from which a free channel is borrowed. Simulation results show that the proposed scheme outperforms existing methods in channel utilization and call blocking probabilities, especially under asymmetric call arrivals with a lower call switching requirement.

I. Introduction

With the explosive growth of cellular radio communication, the frequency spectrum resource allocated to the mobile system is becoming more and more insufficient. The demand for communication capacity is particularly high in metropolitan areas and heavy traffic roads.

One straightforward method to further increase the capacity of cellular radio system is to split a cell into smaller cells. Such a microcellular system can be implemented to a circular highway of a city, downtown area, and other heavy traffic roads.

Another way to increase the capacity of a given cell structure is to adopt a more efficient

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channel assignment scheme. Considering the performance of a channel assignment algorithm, the one-dimensional cell structure provides the easiest experimental environment. The results can then be extended to the higher dimensional microcells.

In this paper, we present a new channel assignment algorithm which is based on the two-step borrowing. The algorithm is compared to an existing method which is shown to be the best in highway radio communication environment.

In Section 2, we review two streams of dynamic channel assignment (DCA). We suggest a new channel allocation scheme in highway microcells in Section 3. In Section 4, various simulation results are provided which show the performance of the proposed DCA algorithm.

Ⅱ. Channel assignment problems

Channel assignment is the allocation of specific frequency channels to cell sites such that the cochannel interference is minimized. In a fixed channel assignment (FCA) algorithm, channels are preassigned to the cell site. Each cell then assigns the fixed channels to vehicles within its cell.

In dynamic channel assignment (DCA) algorithms [4, 7, 8, 9], no fixed channels are assigned to a cell. Therefore, any channel can be assigned to the mobile unit if it satisfies the cochannel separation constraint. There are two large streams in DCA. One is DCA based on FCA [1, 10, 11, 12] and another is DCA without channel set separation [2, 3, 5, 6, 7, 8, 9].

In the DCA which is based on FCA, the total available channels are divided into several channel sets and allocated to the microcells. The channels allocated to a cell are classified into standard channels and nonstandard channels. Standard channels are used for the subscribers in the cell. Nonstandard channels, however, can be lent to or borrowed from neighboring cells.

One of the most efficient DCA algorithms which are based on FCA is proposed by Kuck and Wong [12]. They provide an ordered dynamic channel assignment scheme with reassignment (ODCAR) which combines the merits of Engel and Peritsky [11], and Elnoubi et al. [10]. To provide high capacity and to alleviate worst case channel congestion at each cell, channels are assigned in an ordered basis in conjunction with a minimax algorithm under cochannel interference constraints. They applied the scheme to a highway microcellular system and showed significant performance improvements compared to the FCA and the method by [11].

The second stream is the DCA without channel set separation. In a simple form of DCA [7, 8, 9], a channel can be allocated to a cell if it is not used in any of the cells within the minimum cochannel reuse distance.

A timid DCA algorithm [5] suggests that a mobile which requires access, probes selectable channels and seizes a channel if and only if there are no nearby interference. On the other hand, an aggressive DCA [6] permits the mobile to seize a channel even when interference exists, with the expectation that under normal operation, the disturbed mobile can usually locate another channel.

Aggressive DCA algorithms which have lower blocking probability and higher stability are proposed by [2, 5]. The m-Persistent Polite Aggressive (PPA) algorithms where m is the maximum number of channels that access attempts can be made on, however, have difficulties in real implementation. One of them is the assumption that mobiles have the ability to a priori measure all available channels and determine which one to seize.

Ⅲ. Two-step ordered local packing (TOLP) in highway microcells

Consider a two-directional highway which is divided into segments of equal length. Each segment is a microcell with its own base station (BS) located at lamp-post elevations.

For a channel to be assigned for a call setup, it has to satisfy the cochannel separation requirement. It is the minimum distance separation constraint which allows the same frequency to be reused. Assume the cochannel separation requirement is 2S microcells, S microcells to the right and another S microcells to the left. If a call has arrived in microcell *i*, and a channel c is not in use at cells within the cochannel interference zone of cell *i*, then the channel c can be assigned to cell *i*. However, if a cell within the cochannel interference zone is using the channel *c*, then cell *i* must seek for another available channel for the call setup. Figure 1 explains the cochannel separation requirement in a highway system when a DCA algorithm is used. The two-step odered local packing algorithm is based on the two-step borrowing. At each step the lowest number of free channel which satisfies the cochannel separation requirement is borrowed.

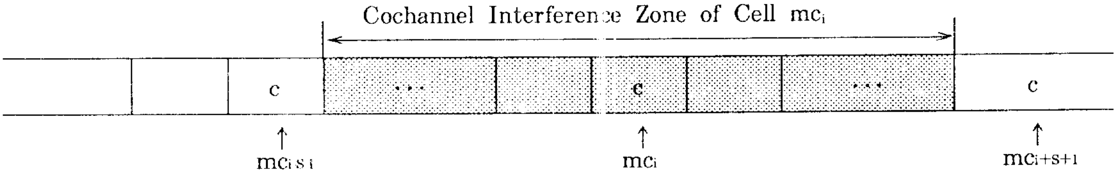

Figure 1. Cochannel interference zone of cell *i*

1. Algorithm

When a channel request arrives, Two-step Ordered Local Packing (TOLP) first finds a free channel under the cochannel separation constraint. If there are free channels the first one of the ordered sequence, i. e. the lowest number of free channel, is selected. All channels are numbered in a predetermined order such as the order of frequency channel bandwidths. They are assumed to satisfy the minimum separation required by the adjacent channel interference [13]. Implementing such an ordered selection facilitates high frequency reuse and thus maximizes the capacity.

Suppose there is no free channel for the call request from cell i. Then within the cochannel interference zone of cell i, TOLP counts for each channel the number of cells which are using the same channel. We call the cell whose counted number is one a neighbor cell of the cell i. Then the channel which is in use in a neighbor cell can be borrowed from cell i, since the channel is not interfered by other cells in the zone. We call this procedure one-step packing. The selection of a neighbor cell will be discussed at the end of this section. If all the neighbor cells of cell i have no free channel in the previous stage, TOLP finds two-step neighbor cells, i. e. the neighbor's neighbor cells. If any of the two-step neighbor cells has a free channel, the ongoing call on the lowest number of channel in the cell is reassigned to the first free channel. Then the freed channel of the two-step neighbor cell is transferred to the neighbor cell of cell i. Finally, the channel used by the neighbor is borrowed from cell i. If no two-step neighbor cell has a free channel, the call request will not be allowed. If the request is a new call, it will be blocked. On the other hand, if it is an existing call, it will be terminated abruptly. The flow chart of this algorithm is shown in Figure 2.

Now, we will discuss the selection criterion of the neighbor cell from which cell i borrows the channel. In the selection of neighbor cell two factors are considered : the number of free channels in the cell and the new call and handoff call arrivals in the cell. These two factors are considered in the criterion value CV to be introduced. Assume the cochannel separation constraint requires to separate S microcells for a channel to be reused. If a call arrives in a cell i and i has no free channel, the following criterion value of a neighbor cell $(i+n)$ is computed for

$-S \leq n \leq S$;

$$CV_{(i+n)} = \frac{FC_{(i+n)}}{\frac{1}{\mu}\sum_{j=-S}^{S} \lambda_{(i+n+j)} \frac{1}{2}\left\{ OC_{(i+n+1)} + OC_{(i+n-1)} \right\}}$$

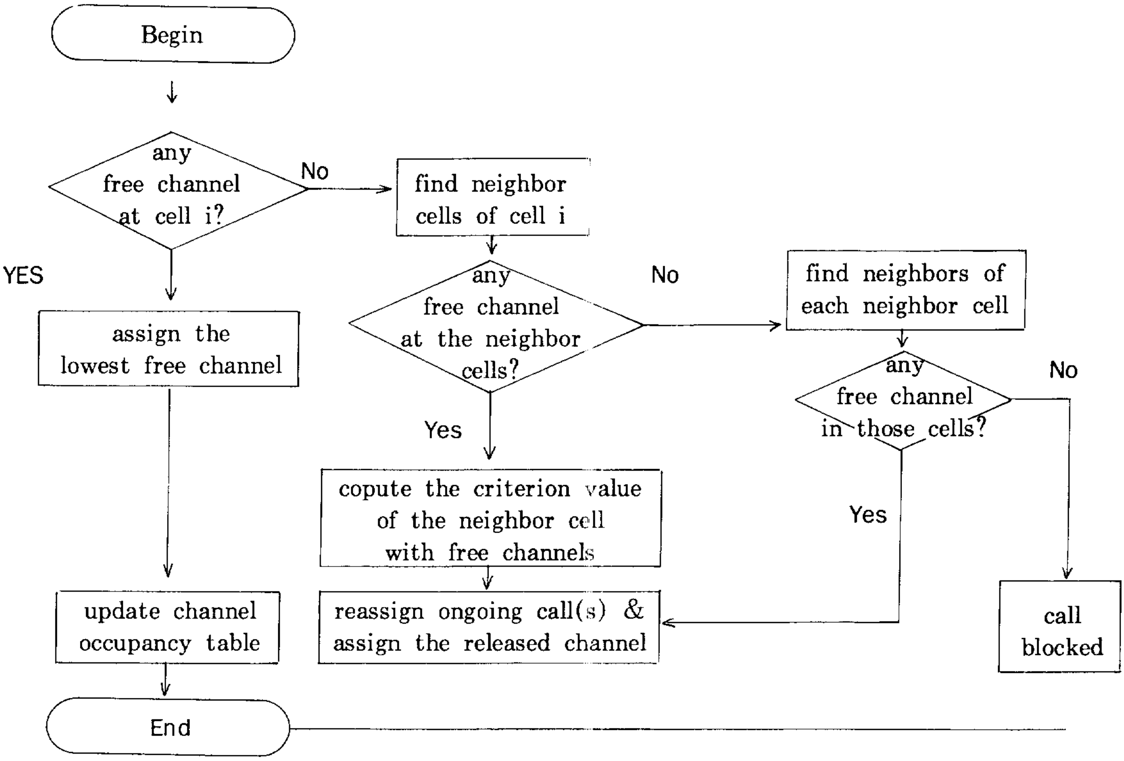

Figure 2. Channel assignment procedure of TOLP

where

$\frac{1}{\mu}$: mean call holding time (seconds)

λ_k : call arrival rate at cell k (call arrivals/s/cell)

FC_k : the number of free channels at cell k

OC_k : the number of occupied channels at cell k

Note that a cell which has many free channels and low call arrival rates can afford to lend channels to neighbors. Thus, it is reasonable to borrow a channel from a neighbor cell whose CV is the highest. Each item of the CV is explained as follows.

The numerator of the criterion value represents the number of free channels at a neighbor cell. The larger the number of free channels, the higher chance the cell has to transfer free channels.

The first term of the denominator represents new call arrival load in Erlang, i. e. the multiplication of call arrival rate and mean call holding time, at a neighbor cell and cells in its cochannel interference zone. Note that a channel which is used in a cell within the cochannel interference zone of the neighbor cell cannot be assigned to cell *i*. Thus the traffic load in cells in the cochannel interference zone has the same effect as the traffic on the neighbor cell itself.

The second term of the denominator is for potential handoff calls in the neighbor cell. A handoff call in a cell is generated from a mobile which moves into the cell. One half of the ongoing calls at adjacent cells is assumed to flow into the neighbor cell. Thus the denominator represents the call arrival load in a neighbor cell. The higher the call arrival load, the lower chance the cell has to transfer free channels.

2. Updating channel occupancy table

For the operation of the TOLP each base station is assumed to have channel occupancy table. The table contains local information necessary for selecting channels. An example of the channel occupancy table is shown in Figure 3. Each column and row corresponds to a channel and a cell respectively. A check mark in a cell indicates a channel occupied by the cell. The last three columns facilitate the computation of criterion values.

A channel at cell i is available only when the channel is not occupied by any of the 2S adjacent cells, i. e., i+1, i+2,⋯ ,i+S and i−1, i−2,⋯ ,i−S. The content of the table is updated by collecting channel occupancy information from related microcells. In the two-step local packing a cell requires information of neighbors of each neighbor cell. Thus a base station, when seizing or releasing a channel, has to send this information to its (4S+2) adjacent cells.

3. Examples of TOLP

Figure 3 shows an example of the one-step packing of the TOLP. Suppose that there are 50 channels in a system and that cochannel separation requirement is 4 microcells. Also, assume the call arrival rate at each microcell is 0.05 call arrivals/s/cell and average call duration is 120 seconds. If a call request arrives at cell *i* in the figure, there is no free channel for the request. In the cochannel interference zone of cell *i* in Figure 3, note that channels 5, 7, 6, 50 and 3 are used only in cells $i-4$, $i-2$, $i+1$, $i+2$ and $i+3$, respectively. Thus the neighbor cells of cell *i* are cell $i-4$, $i-2$, $i+1$, $i+2$ and $i+3$. The criterion values of the five neighbor cells are computed as $10/(120*0.05*9+1/2(6+15))=0.155$, 0.203, 0.104, 0.126 and 0.217, respectively. Thus, cell $i+3$ is selected as the cell from which a channel is borrowed. The call on channel 3 at cell $i+3$ is reassigned to the lowest number of free channel 5. As a result, channel 3 is transferred to the call request at cell *i*.

	1	2	3	4	5	6	7	8	…	50	# of free channels	# of ongoing calls	call arrivals/s/cell
i−9	*				*	*		*			12	5	0.05
i−8				*							10	7	0.05
i−7			*								13	5	0.05
i−6											13	6	0.05
i−5		*									13	6	0.05
i−4					*			*			10	3	0.05
i−3				*							7	15	0.05
i−2							*				14	7	0.05
i−1											0	15	0.05
i	*	*									0	20	0.05
i+1						*					7	11	0.05
i+2								*		*	8	7	0.05
i+3			*	*							13	8	0.05
i+4											10	5	0.05
i+5		*									12	7	0.05
i+6											11	8	0.05
i+7											12	7	0.05
i+8	*		*								10	6	0.05
i+9				*							11	4	0.05

Figure 3. Channel occupancy table for an example of one-step packing

In case of no free channels at neighbor cells of cell *i*, the TOLP looks for neighbors of each neighbor cell. Figure 4 shows an example of the two-step ordered local packing.

In the figure, neighbor cells *i*−2, *i*+2 of cell *i* have no free channels. However, neighbor cell *i*−3 of cell *i*−2 has a free channel. Thus, the TOLP transfers the call request on channel 3 at cell *i*−3 to the first free channel, i. e. the channel 5 to make a free channel for cell *i*−2. Cell *i*−2 then takes the freed channel 3 and reassigns the call on channel 7 to channel 3. As a consequence cell *i* acquires channel 7 for the call.

	1	2	3	4	5	6	7	8	…	50	# of free channels	# of ongoing calls	call arrivals/ s/ cell
i−9	*		*								6	3	0.05
i−8				*							4	4	0.05
i−7											6	5	0.05
i−6											5	6	0.05
i−5		*									3	6	0.05
i−4						*		*			1	9	0.05
i−3			*	*							1	8	0.05
i−2							*				0	11	0.05
i−1											0	10	0.05
i	*	*									0	9	0.05
i+1						*					0	12	0.05
i+2					*					*	0	9	0.05
i+3			*	*				*			0	11	0.05
i+4											0	9	0.05
i+5		*					*				0	8	0.05
i+6											4	6	0.05
i+7											5	7	0.05
i+8	*		*								4	5	0.05
i+9											5	4	0.05

Figure 4. Channel occupancy table for an example of two-step packing

IV. Computational results and discussion

The simulation model is made up of a highway microcellular system where the length of each microcell is 2km. Each direction is assumed to have the same traffic volume.

The new call arrival rate is assumed to follow Poisson distribution. The call duration has an exponential distribution with a mean of 120 seconds. The vehicular speeds are modeled using a truncated Gaussian distribution with a mean value of 100km/h, a standard deviation of 40km/h, a maximum speed of 200km/h, and a minimum speed of 20km/h.

For the asymmetric traffic load, the vehicles are decelerated from their original free-flowing speed to a predetermined congestion speed before entering the congested microcell. These vehicles are accelerated to their former free-flowing speed when they leave the congested microcell. Various new call arrival rates are experimented in the congested cells. The call arrival rate in regular cells is assumed 0.04 call arrivals/s/cell.

The total number of available channels is 50. The cochannel separation requirement is four microcells both to the right and left which is equivalent to the five-channel set configuration in ODCAR [12]. Twenty microcells are considered in the simulation.

To test and compare the performance of the proposed channel assignment algorithm the following measures are employed.

- New call blocking probability :

$$P_N = \frac{\text{Total Number of New Calls Blocked}}{\text{Total Number of New Call Arrivals}}$$

- Hand-off call drop probability :

$$P_H = \frac{\text{Total Number of Handoff Failures}}{\text{Total Number of Handoff Requests}}$$

- Grade of service (GOS) :

$$GOS = \frac{P_N \lambda_N}{\lambda_N + \lambda_H} + \frac{P_H \lambda_H}{\lambda_N + \lambda_H}$$

where λ_N is new call arrival rate and λ_H is handoff arrival rate.

- Switchings/call : the number of switchings implemented in order to serve a call.

1. Simulation with symmetric call arrivals at each cell

The performance of the proposed TOLP scheme is compared with FCA and ODCAR [12].

Figure 5 and 6 show the call blocking probabilities of three schemes at various levels of new call arrival rates. Minor improvement in blocking probabilities is obtained by the TOLP compared to the ODCAR at each level of the call arrival rate. Since the ODCAR is based on the FCA which allocates channel sets according to the minimum reuse interval, the cochannel reuse distance may exceed the minimum interval in real implementation.

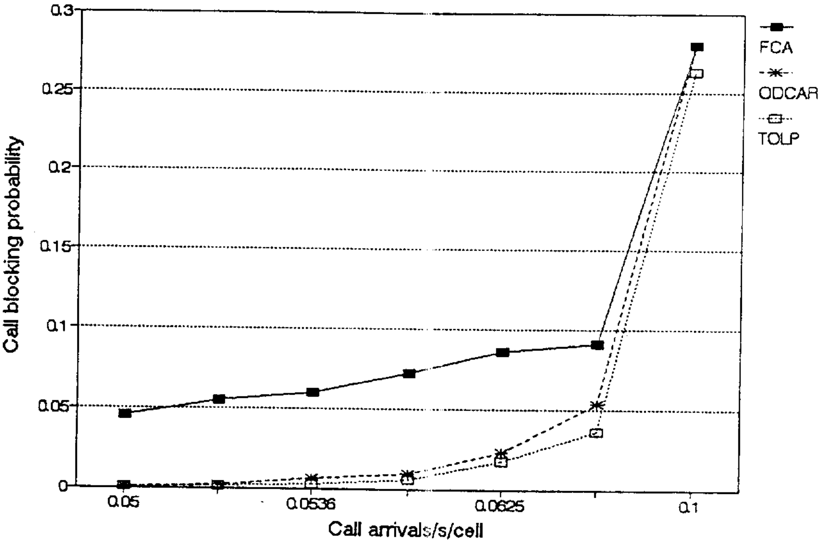

Figure 5. New call blocking probability
(Symmetric call arrivals)

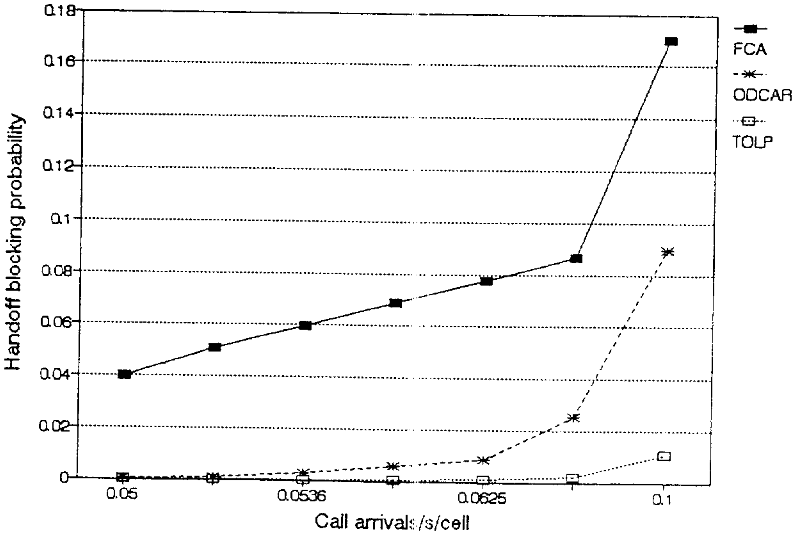

Figure 6. Handoff call drop probability
(Symmetric call arrivals)

However, in the TOLP, since channels are not fixed as either standard or nonstandard, they may be tightly packed to each call as far as the cochannel separation requirement is satisfied.

The amount of teletraffic carried in Erlangs, under symmetric call arrivals is shown in Figure 7. For a fixed GOS, the proposed dynamic scheme provides higher carried traffic than the FCA. However, the improvement is not noticeable when compared to the ODCAR.

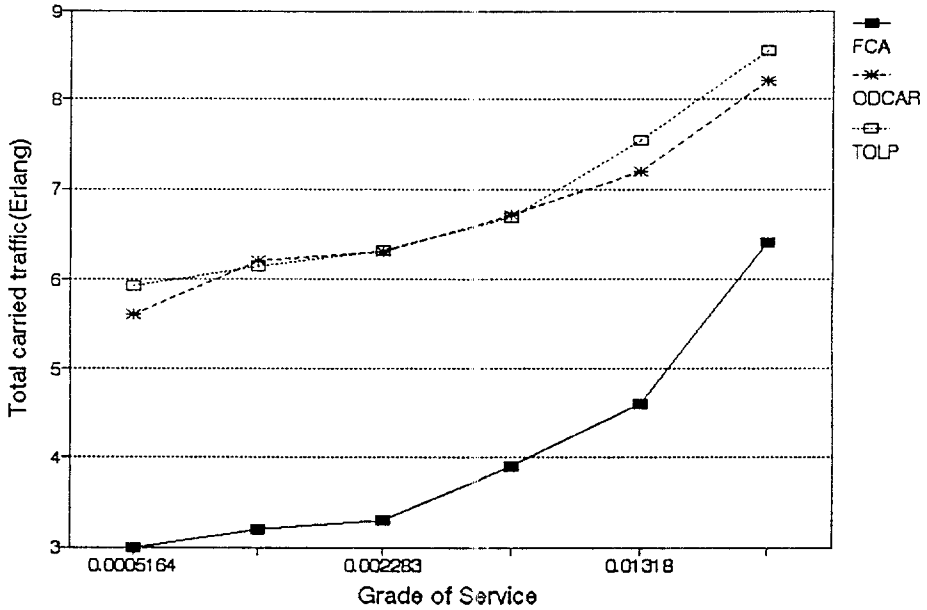

Figure 7. Total carried traffic
(Symmetric call arrivals)

The number of required switchings for each call setup is illustrated in Figure 8. On the average, two to three switchings are required in FCA. This is a justifiable result from the conditions simulated, i. e., 120 second mean call holding time, 100k/h mean mobile speed and 2km cell length. The figure shows that approximately five switchings are needed per call in ODCAR. This increase is largely due to the reassignment of calls from high ordered standard channels to low ordered ones to maintain the ordered sequence of occupied channels. When a call on a standard channel is terminated, the call on a nonstandard channel is reassigned to the released standard channel. This causes another switching in the cell where the released nonstandard channel is a standard channel.

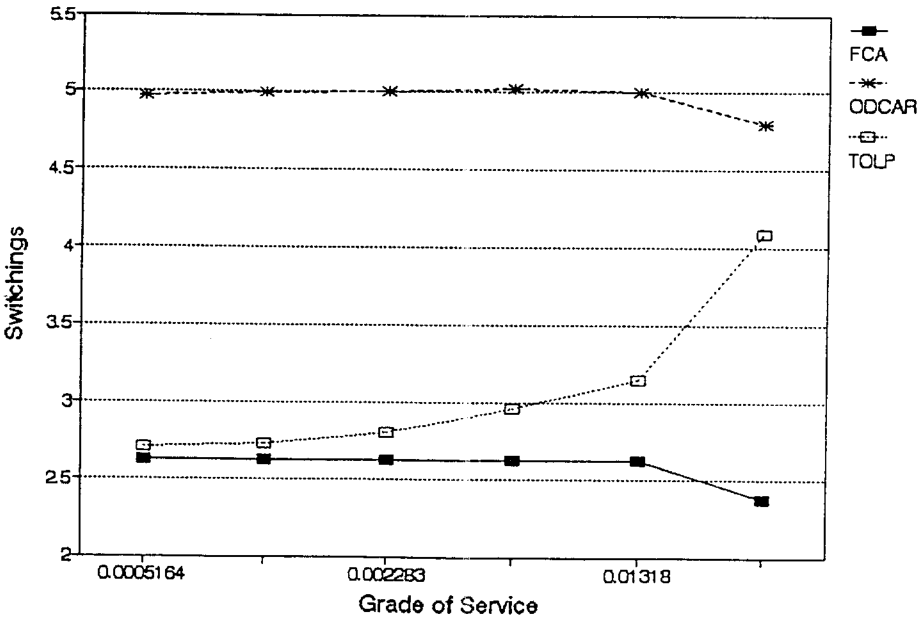

Figure 8. Average switchings/ call
(Symmetric call arrivals)

The slope of the TOLP increases according to the GOS levels. In TOLP two and three switchings are executed per one-step and two-step packing respectively. As call arrival rate goes up, the two-step packing will be generated more often. Note that high call arrival rate is consistent with high call blocking probability which is consistent again with high value of GOS. Therefore as the level of GOS increases the number of switchings in TOLP also increases.

2. Simulation with asymmetric call arrivals at each cell

Asymmetric teletraffic situation is simulated, where the new call arrival rate at the congested microcell is higher than its surrounding microcells, which have an arrival rate of 0.04 call arrivals/s/cell.

Figure 9 and Figure 10 indicate the new call and handoff call blocking probability respectively. It is clear from the figures that the performance of ODCAR deteriorates rapidly as the congestion increases. The superiority of TOLP to ODCAR is much more prominent in asymmetric call arrivals than in symmetric situation.

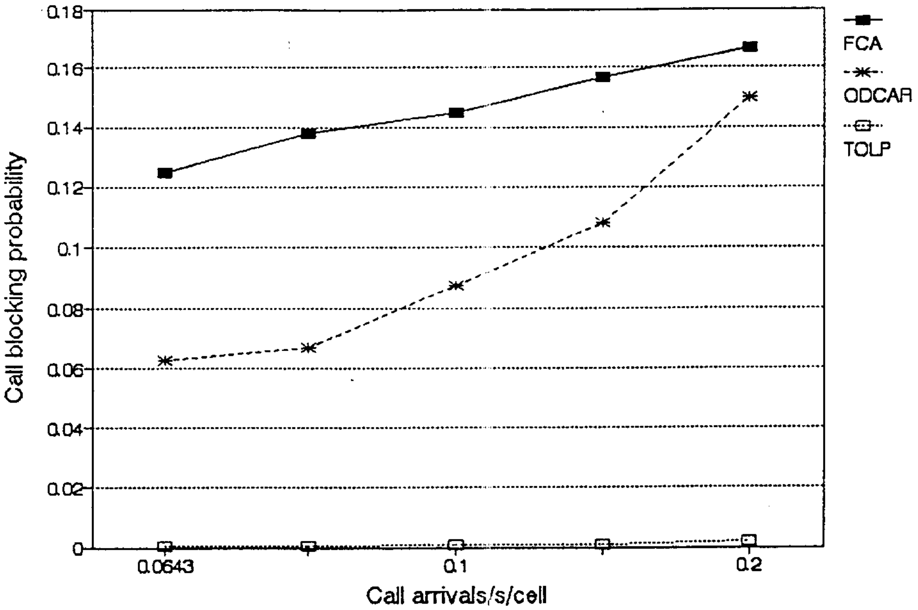

Figure 9. New call blocking probability
(Asymmetric call arrivals)

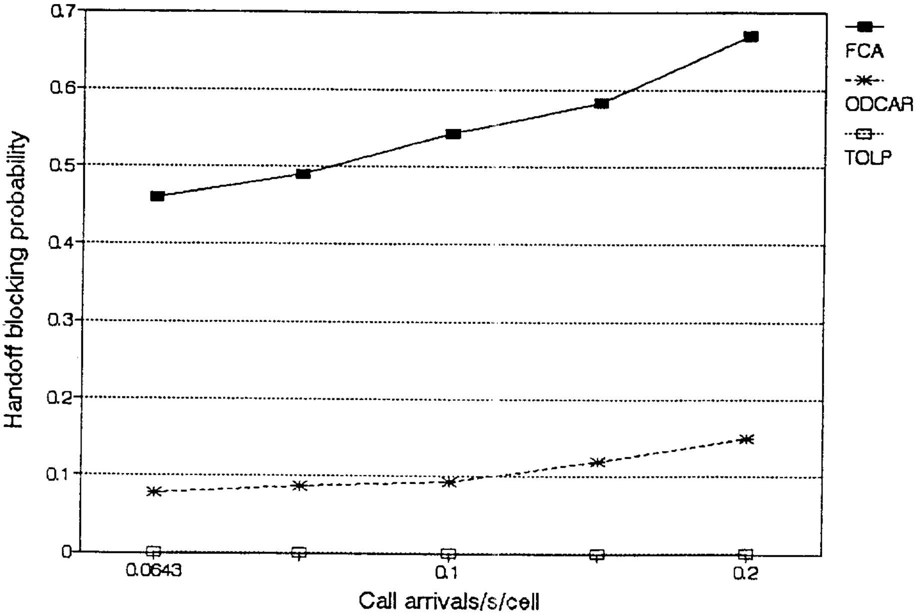

Figure 10. Handoff call drop probability
(Asymmetric call arrivals)

V. Conclusion

An efficient dynamic channel assignment algorithm at highway microcells is presented. In the scheme two-step reassignment are used to increase the channel utilization in congested microcell region. To decide the cell from which a free channel is borrowed, a cell selection criterion is suggested. Most desirable cell is determined by considering the call arrival rate and number of free channels at the cell and the traffic load at adjacent two cells.

Computational result shows that the proposed scheme outperforms FCA and ordered dymamic channel assignment scheme with reassignment (ODCAR) [12]. The new call and handoff blocking probability is overwhelmingly reduced in asymmetric call arrivals compared to the ODCAR. The new call blocking probability by ODCAR is approximately twice of that by TOLP when the call arrivals at each cell are less than 0.1/second. The gap between the two methods is serious in the call drop probability of handoff calls. The result shows that the approximate handoff call drop probability by ODCAR is 55% while that by TOLP is 10% at 0.1 call arrivals/s/cell.

The prominance of the proposed scheme is also illustrated in the number of required switchings for each call setup. On the average five switchings are required in ODCAR while three in the proposed TOLP. This is mainly due to that the channels are not partitioned into standard and nonstandard in TOLP. The partition of channels in ODCAR brings about many switchings in cells where the released nonstandard channels are standard.

The addition of three or more step reassignment in the procedure is expected to increase the channel utilization in congested microcell region. However, the addition may increase the computational burden at each base station. Also, the performance of the proposed TOLP and the addition of the three step reassignment has to be compared with respect to the real time control of the channel assignment algorithm for the real implementation.

Finally, for the application of the proposed algorithm at highway intersection or downtown area further consideration needs to be done for the cochannel interference zone. Since the distribution of cells near the intersection is two dimensional, the cochannel interference region is expanded to cells at another crossing highway or street. Therefore, the expanded cochannel interference zone has to be included in the channel occupancy table at each cell near the intersection. The information of expanded cochannel interference region has also to be included in the computation of the criterion value to select the neighbor cell from which a channel is borrowed.

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