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A Multihop Dynamic Channel Assignment Scheme For Cellular Network

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Abstract

A multihop Dynamic Channel Assignment Scheme is proposed here for Multihop Cellular network. The proposed scheme splits the cell into microcell and macrocell to accept and complete the call as single hop, two hops, or three hops call. The radio resources are assigned to each call based on the interference information in the surrounding cells, stored in Interference Information Table at MSC. Two different channel searching algorithms, namely, Sequential Channel searching and packing based Channel searching are proposed and studied here. Such schemes with channel re-assignment procedure to further enhance the system performance, is also investigated. The MDCA scheme for significant improvement of system capacity and call blocking probability is simulated and studied. Further the situation of Hot-Spot is also studied for avoiding call blocking.

Index Terms — Multihop Cellular Network, Channel Assignment, Mobile Ad-Hoc Networks, Clusters.

1. Introduction

Traditional 2G Cellular networks are expanding exponentially and has almost 4 billion of subscriber till now [1]. Essentially we have a limited resource transmission spectrum that must be shared by several users. Each cell is allocated a portion of the total frequency spectrum. As users move into a given cell, they are then permitted to utilize the channel allocated to that cell. As users move into a given cell, they are then permitted to utilize the channel allocated to that cell [2]. The virtue of the cellular system is that different cells can use the same channel given that the cells are separated by a minimum distance according to the system propagation characteristics; otherwise, intercellular or co channel interference occurs. Such channel allocation technology is a matured technology and quite successful also, beside a drawback of call blocking and inability to handle different spatial traffic demands. In such situations, Mobile Adhoc Networks (MANETs) are appropriate choice, but they also have their own demerits. TCNs have mature technology support for reliable performance. However, building and expanding their necessary infrastructure is costly. MANETs, on the other hand, are simple to deploy and easily expandable. Nevertheless, many of their implementation issues are still in the research phase. By taking into account the advantages and drawbacks of TCNs and MANETs, researchers notice that a combination of them is the logical solution to the next generation mobile networks. In 1996, Adachi and Nakagawa raised the concept of cellular ad-hoc united communication system [3]. Subsequently, many similar proposals were reported, such as multihop cellular network (MCN) [4]. MCN-type systems are expected to bring considerable amount of benefits. However, with the limited bandwidth for cellular communications, channel assignment becomes even more challenging in MCN-type systems [5].An ad hoc GSM (A-GSM) protocol is proposed for using the cellular frequency band for relay stations (RSs) to relay traffic [6]. However, the study did not clearly address how the resources are allocated to the BS and RSs. Recently; clustered MCN (CMCN) has been proposed and studied using a fixed channel assignment (FCA) scheme [7]. It uses cellular frequency band for traffic relaying. Results show that CMCN with FCA can improve the system capacity [8]. However, FCA is not able to cope with temporal changes in the traffic patterns and thus may result in deficiency. Moreover, it is not easy to obtain the optimum channel assignment for uplink and downlink under FCA, which is used to achieve the lowest call blocking probability. Therefore, dynamic channel assignment (DCA) is more desirable [9].

In this paper, we propose a Multihop Dynamic Channel Assignment scheme that is based on Interference Information Table [10] stored at MSC for each cell. Two different channel searching algorithms, namely, Sequential Channel searching and packing based Channel searching are proposed and studied here. Such schemes with channel re-assignment procedure to further enhance the system performance, is also investigated. The MDCA scheme for significant improvement of system capacity and call blocking probability is simulated and studied. Further the situation of Hot-Spot is also studied for avoiding call blocking.

2. Clustered Multihop Cellular Network

The basic idea behind the CMCN is to divide the cell into hierarchical overlaid system of microcell and macrocell [11] by integrating MANET clustering in to the TCN [12]. BS in TCNs covers the entire macrocell with a radius rM .The transmission ranges of traffic and control channels are the same and equal to rM for both the BSs and MSs. In CMCN, a macrocell is divided into seven microcells with a radius of rm. Each virtual microcell can be divided into two regions: inner half and outer half. The inner half is near the central microcell. The transmission range of the traffic channels in CMCN for both the BSs and MSs is equal to rm. The transmission range of the control channels for the BSs and MSs is equal to rM so that the BS can communicate with all the MSs within its macrocell area for control information exchange.

3. Proposed MDCA Scheme

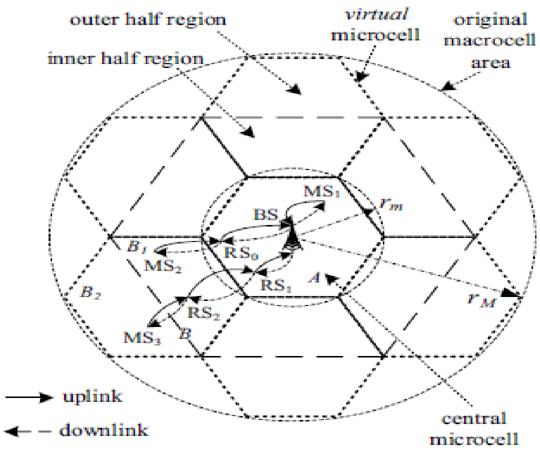

Fig. 1. Channel Assignment in CMCN

Figure 1 shows typical channel assignment scheme used in CMCN. The scheme assigns radio resources to a particular call in a cell depending on the following type of classification of call initiated.

3.1 One Hop Call

The one hop call refers to call originated from MSs in a central micro cell A in figure 1. It requires one uplink channel and one down link channel free in microcell A. The call is accepted if microcell has at least one free uplink channel and one free downlink channel, otherwise, call is blocked.

3.2 Two hop call

Two hop calls refers to call originated from MSs in the inner half region of a virtual microcell, such as MS2 in region B1 of microcell B in Fig. 1. The BS is able to find another MS, RS0, in the central microcell acting as a RS. For uplink transmission, a two-hop call requires one uplink channel from the microcell B, for the transmission from MS2 to RS0, and one uplink channel from the central microcell A, for the transmission from RS0 to the BS. For downlink transmission, a two-hop call requires two downlink channels from the central microcell A, for the transmission from the BS to RS0, and from RS0 to MS2, respectively. A two-hop call is accepted if all the following conditions are met: (i) there is at least one free uplink channel in microcell B; (ii) there is at least one free uplink channel in the central microcell A; and (iii) there are at least two free downlink channels in the central microcell A. Otherwise, the call is blocked.

3.3 Three Hop Call

Three-hop calls refer to calls originated from MSs in the outer half region of a virtual microcell, such as MS3 in region B2 of microcell B in Fig. 1. The BS is responsible for finding two other MSs, RS1 and RS2, to be the RSs for the call; RS1 is in the central microcell A and RS2 is in the region B1. For uplink transmission, a three-hop call requires two uplink channels from microcell B and one uplink channel from the central microcell A. The three uplink channels are used for the transmission from MS3 to RS2, from RS2 to RS1 and RS1 to the BS, respectively. For downlink transmission, a three-hop call requires two downlink channels from central microcell A and one downlink channel from microcell B. A three-hop call is accepted if all the following conditions are met: (i) there is at least one free uplink channel in the central microcell A; (ii) there at least two free uplink channels in the microcell B; (iii) there are at least two free downlink channels in the central microcell A; and (iv) there is at least one free downlink channel in microcell B. Otherwise, it is blocked.

As it is clear, the channel assignment scheme is unbalanced in a sense that, no. Of uplink and downlink channel channels assigned to a call are unequal. This is something different from a TCN, where same no. of uplink and downlink channels is allotted to every call [9].

3.4 Interference Information Table

	Channel				
Cell	1	2	3	...	N
0	L	L	2L	...	L
1		2L	U_{22}	...	U_{33}
2	L	L	2L	...	2L
3	L	U_{11}	2L	...	L
...	...	...	...	...	...
12		U_{11}	U_{11}	...	L
...	...	...	...	...	...
48	U_{22}	L	U_{33}	...	

Table 1. Interference Information Table

The proposed MDCA scheme works on the information provided by the Interference Information Table (IIT) [10]. Two global IITs are stored in mobile switching centre (MSC) for uplink and downlink channels. Every BS is able to access to the global IITs. Denote the set of interfering cells of any microcell A as I(A). The information of I(A) is stored in the Interference Constraint Table (ICT). Different reuse factor Nr values will have different I(A) for a given microcell A and we can implement MDCA with any Nr by changing the interfering cells information in the ICT. Table I shows the uplink IIT for the CMCN shown in Fig. 2, which includes the shared N system uplink channels in each cell. The downlink IIT is similar and hence not illustrated here. The content of an IIT is described as follows.

1) Used Channels: a letter 'U11/22/33' in the (microcell A, channel j) box signifies that channel j is a used channel in microcell A. The subscript indicates which hop the channel is used for; 'U11', 'U22', 'U33' refer to the first-hop channel, the second-hop channel and the third-hop channel, respectively.

2) Locked Channels: a letter 'L' in (microcell A, channel j) box signifies that microcell A is not allowed to use channel j due to one cell in I(A) is using channel j. Similarly, 'nL' in (microcell A, channel j) box indicates n cells in I(A) are using channel j.

3) Free Channels: an empty (microcell A, channel j) box signifies that channel j is a free channel for microcell A.

3. Channel Searching Strategies

1) Sequential Channel Searching (SCS): When a new call arrives, the SCS strategy is to always search for a channel from the lower to higher-numbered channel for the first-hop uplink transmission in the central microcell. Once a free channel is found, it is assigned to the first-hop link. Otherwise, the call is blocked. The SCS strategy works in the same way to find the uplink channels for second- or third-hop links for this call if it is a multihop call. The channel searching procedure is similar for downlink channel assignment as well.

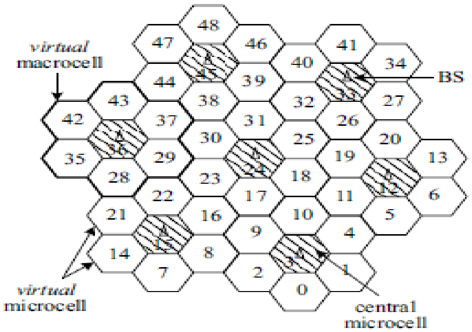

Figure 2. Simulated 49 Cell Network

2) Packing-Based Channel Searching (PCS): The PCS strategy is to assign microcell A a free channel j which is locked in the largest number of cells in I(A). The motivation behind PCS is to attempt to minimize the effect on the channel availability in those interfering cells. We use F(A, j) to denote the number of cells in I(A) which are locked for channel j by cells not in I(A). Interestingly, F(A, j) is equal to the number of cells in I(A) with a label 'L' in channel j's column in the IIT. Then the cost for assigning a free channel j in microcell A is defined as,

$$E(A,\ j) = I(A) - F(A, j) \quad \text{-------------(1)}$$

If there is more than one such channel, the lower-numbered channel is selected. For example, Table II shows a call in cell 15 requesting a first-hop channel. Channels 1, 2 and 3 are the three free channels in cell 15. Refer to Fig. 2, I(15) = 2, 7, 8, 9, 13, 14, 16, 17, 20, 21, 22, 23, 27, 28, 29, 34, 47, 48 with Nr = 7. Since most of the cells in I(15) are locked for channel 2, it is suitable to assign channel 2 as the first-hop channel in cell 15 because F(15, 2) = 15 is largest among the F(15, j) values for j = 1, 2 and 3. The best case solution is when E(A, j) = 0. However, it might not be always feasible to find such a solution. The proposed PCS strategy attempts to minimize the cost of assigning a channel to a cell that makes E(A, j) as small as possible. Thus, it results in a sub-optimal solution.

4. Channel Updating

1) Channel Assignment: when the BS assigns the channel j in the microcell A to a call, (i) it will inform the MSC to insert a letter 'U11/22/33' with the corresponding subscript in the (microcell A, channel j) entry box of the IIT; and (ii) it will also inform the MSC to update the entry boxes for (I(A), channel j) by increasing the number of 'L'.

2) Channel Release: when the BS releases the channel j in the microcell A, (i) it will inform the MSC to empty the entry box for (microcell A, channel j); and (ii) it will also inform the MSC to update the entry boxes for (I(A), channel j) by reducing the number of 'L'.

5. Channel Re-Assignment

When a call using channel i as a kth-hop channel in microcell A is completed, that channel i is released. The MSC will search for a channel j, which is currently used as the kth-hop channel of an ongoing call in microcell A. If E(A, i) is less than E(A, j), the MSC will reassign channel i to that ongoing call in microcell A and release channel j. CR is only executed for channels of the same type (uplink /downlink) in the same microcell. Thus, CR is expected to improve the channel availability to new calls. Mathematically, the motivation behind CR can be expressed as a reduction in the cost value:

$$\begin{aligned}\Delta E(A,\ i \rightarrow j) &= E(A,\ i) - E(A,\ j)\\ &= F(A,\ j) - F(A,\ i) < 0\end{aligned} \quad \text{--------- (2)}$$

6. Simulation Results

6.1 Simulation Model

The simulated network is shown in Fig. 2, and the wraparound technique is used to avoid the boundary effect. The number of system channels is N=70 (70 uplink channels and 70 downlink channels). We use Nr=7 as illustration, hence a channel used in cell A cannot be reused in the first and the second tier of interfering cells of A, i.e. two-cell buffering. Two traffic models are studied: uniform traffic model generates calls which are uniformly distributed according to a Poisson process with a call arrival rate λ per macrocell area, while hot-spot traffic model only generates higher call arrival rate in particular microcells. Call durations are exponentially distributed with a mean of 1/μ. The offered traffic to a macrocell is given by ρ = λ/μ. Each simulation runs until 100 million calls are processed. The 95% confidence intervals are within ±10% of the average values shown. For the FCA in TCNs, the results are obtained from Erlang B formula with N/7 channels per macrocell.

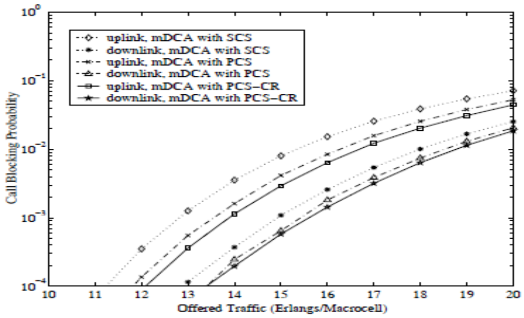

Fig. 3. Asymmetric capacity for uplink/downlink for CMCN using MDCA.

6.2 Simulation With Uniform Traffic

Fig. 3 shows both the uplink and downlink call blocking probability, i.e. Pb,U and Pb,D. Notice that the Pb,U is always higher than the Pb,D due to the asymmetric nature of multihop transmission in CMCN that downlink transmission takes more channels from the central microcell than uplink transmission. The channels used in the central microcells can be reused in the other central microcells with minimum reuse distance without having to be concerned about the co-channel interference constraint, because two-cell buffering is already in place. The system capacity based on Pb,U = 1% for MDCA with SCS and PCS are 15.3 and 16.3 Erlangs, respectively. With PCS-CR (channel reassignment), the capacity of MDCA is increased by 0.4 Erlangs.Fig. 4 shows the average call blocking probabilities for FCA and DCA-WI for TCNs [10], AFCA for CMCN [9], MDCA with SCS, PCS and PCS-CR. DCA-WI, known as DCA with interference information, is a distributed network-based DCA scheme for TCNs. Under DCA-WI, each BS maintains an interference information table and assigns channels according to the information provided by the table. Only the Pb,U for MDCA is shown because uplink transmission has lower capacity. At Pb,U = 1%, the system capacity for the FCA and DCAWI are 4.5 Erlangs and 7.56 Erlangs, respectively. AFCA with optimum channel combinations, (NU,c=22, NU,v=8) and (ND,c=40, ND,v=5), can support 9.3 Erlangs. The MDCA with SCS, PCS, and PCS-CR can support 15.3 Erlangs, 16.3 Erlangs and 16.7 Erlangs, respectively. As compared to DCAWI and AFCA, the improvements of MDCA with PCS-CR are 120.9% and 79.6%, respectively.

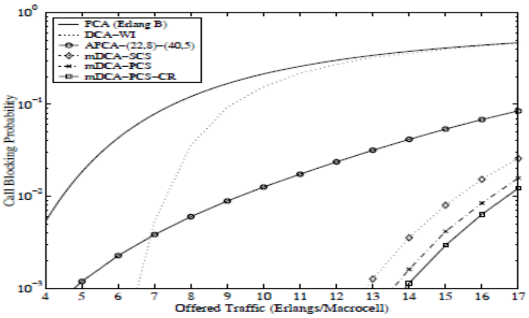

Fig. 4. Capacity comparison with *N*=70.

6.3 Simulation results with Hot-Spot

As in [14], we adopted the same methodology to simulate the hot-spot scenarios. Two scenarios are studied. From Fig. 2, microcell 24 is chosen for the isolated one hot-spot model and microcells 2, 9, 17, 24, 31, 39, 46 are chosen to form the expressway model. First, each of the seven macro cells is initially loaded with a fixed nominal amount of traffic, which would cause 1% blocking if the conventional FCA were used.Next, we increase the traffic load in hot-spot microcells until the call blocking in any microcell reaches 1%. Then we can obtain the capacity values for the hot-spot microcell areas. With N = 70, each of the seven macro cells will be initially loaded at 4.46 Erlangs. For the isolated one hot-spot model, FCA, AFCA and MDCA supports about 0.6 Erlangs, 9 Erlangs and 38 Erlangs per microcell, respectively. For the expressway model, FCA, AFCA and MDCA supports about 0.6 Erlangs, 1 Erlangs and 6 Erlangs per microcell, respectively. It can be seen that MDCA has a huge capacity to alleviate the blocking in hot-spot cells.Significant capacity improvements of MDCA have been observed with a larger N, e.g. N = 210, with uniform and hop spot traffic. Due to limited space, the results are not shown here.

7. Conclusion

The feasibility of applying DCA scheme for MCN-type systems is investigated. A multihop DCA (MDCA) scheme with two channel searching strategies is simulated for clustered MCN (CMCN). A channel reassignment procedure is investigated. Results show that MDCA can improve the system capacity greatly as compared to FCA and DCA-WI for TCNs and AFCA for CMCN. Furthermore, MDCA can efficiently handle the hot-spot traffic.

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