Analysis of Multihop DCA for Cellular Networks with Different Reuse Factors

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1

Abstract

Today's cellular network utilizes dynamic channel allocation system that has threats of high call blocking probability that always yields into forced call drop or termination. To cop up with the problem, we propose an efficient dynamic channel allocation scheme, which is based on carrier to noise interference ratio. A clustered Multihop Cellular Network with FCA and Nr=7 was studied earlier. Its performance was not up to the mark. We propose here a MDCA scheme with knowledge of information about interference in the surrounding cells with different reuse factors. Simulation results shows that capacity improvement at call blocking probability is 1% for MDCA over the conventional FCA are 96% and 210% for Nr=4 and Nr=7, respectively.

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

1. Introduction

Traditional 2G Cellular networks are expanding exponentially and have almost 4 billion of subscribers 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. To meet the demands of increasing wireless access Hsu and Lin pro- posed multihop cellular network (MCN) [1]. As users move into a given cell, they are then permitted to utilize the channel allocated to that cell. To incorporate flexibility of Ad-Hoc and Traditional networks MCN were proposed, which uses multihop transmission for peer to peer mobile communication [2]. Therefore, channel assignment for this promising net- work architecture becomes even more difficult.

Recently, a number of MCN architectures have been proposed and studied. For iCAR [3], fixed ad hoc relay stations (ARSs) are deployed to enable traffic balancing. iCAR is based on the idea of diverting the traffic from congested cells to non-congested cells using unlicensed frequency band other than the cellular frequency band, such as the industrial, scientific and medical (ISM) band. The communication link between MSs and relay stations (RSs) uses the ISM band. In [4], Yanmaz and Tonguz found that the efficiency of iCAR is dependent on the number of available ISM relay channels (CHs). Next, UCAN [5] is to increase the user data rate and system throughput through multihop relaying using the ISM band as well. In these papers, there is no detailed description on how to select and allocate the relay CHs to a MS/RS for each hop. In [6], an ad hoc GSM (A-GSM) protocol was proposed to use the cellular frequency band for RSs to cover dead spots and increase the system capacity. However, it did not clearly address how the resources are allocated to MSs and RSs. Similarly, MCN proposed in [1] also uses the cellular frequency band to implement multihop transmission, but no detailed description of channel assignment is provided.

In our recent work [7], clustered MCN (cMCN) is proposed and studied using fixed channel assignment (FCA). It uses cellular frequency band for traffic relaying. Results shows that cMCN with FCA can improve the channel capacity. But, FCA can not deal with problems like temporal traffic demands and hot-spot. DCA is more preferable in such varying traffic demand pattern. In addition, the proposed asymmetric FCA (AFCA) for cMCN in is limited to a reuse factor of 7. Other reuse factors are not applicable. Therefore, we propose a DCA in CMCN with Multihop transmission applicable with any reuse factor.

2. Clustered Cellular Network with Multihop Transmission

The objective of cMCN is to achieve the characteristics of the macrocell / microcell hierarchically overlaid system by applying MANET clustering [7]. In SCNs, the BS will cover the whole macrocell with a radius of $r_{M,}$ while cMCN divides the macrocell area into seven microcells with a radius of r_m as shown in Fig. 1. Six *virtual* microcells will be formed around the central microcell. We use a dedicated information port (DIP), located at the center of each *virtual* microcell, as a cluster head. The function of a DIP is to allocate CHs to the MSs within its *virtual* microcell, to select a MS as a RS, to determine the routing path and to help its BS on the functions of authentication, authorization, and accounting (AAA). Different from the ARSs in iCAR [3], DIPs are not involved in data relaying. Therefore, their complexity is much lower than a BS, so does the cost. Each *virtual* microcell can be divided into two regions: inner half and outer half. The inner half is near the central microcell.

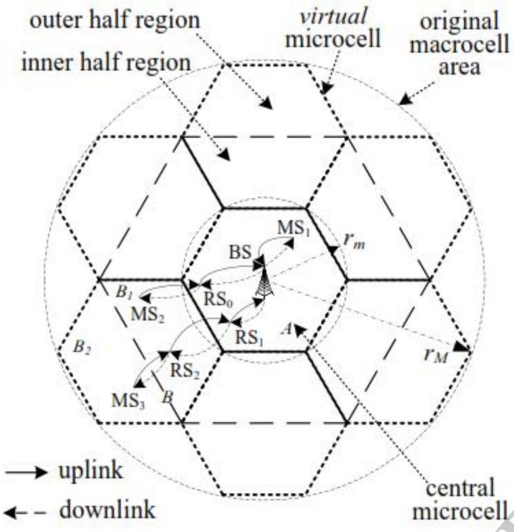

Figure 1. Channel assignment in cMCN with mDCA.

3. Proposed DCA with Multihop

First, we look at the channel assignment procedure under mDCA, which is shown in Fig. 1 and described as follows.

1) One-hop Calls: A call originated from a MS in the central microcell, e.g., MS_1 in microcell *A*, is considered as a one- hop call. It requires one UL CH and one DL CH from the microcell *A*. The call is accepted if microcell *A* finds one free UL CH and one free DL CH. Otherwise, the call is blocked.

2) Two-hop call: A call originated from a MS in the inner half region of a *virtual* microcell, e.g., MS_2 in region B_1 of microcell *B*, is considered as a two-hop call. The BS will find another MS in microcell *A* as a RS, e.g., RS_0 in Fig. 1. For UL transmission, a two-hop call requires one UL CH from the microcell *B* and one UL CH from microcell *A*. The CHs are used for the transmission from MS_2 to RS_0 and from RS_0 to the BS, respectively. For DL transmission, a two-hop call requires two DL CHs from microcell *A*; one CH is for the transmission from the BS to RS_0 and the other is for that from RS_0 to MS_2. The call is accepted if all the following conditions satisfy: (i) microcell *B* finds one free UL CH; (ii) microcell *A* finds one free UL CH; and (iii) microcell *A* finds two free DL CHs. Otherwise, the call is blocked.

3) Three-hop Calls: A call originated from a MS in the outer half region of a *virtual* microcell, e.g., MS_3 in region B_2 of microcell *B*, is considered as a three-hop call. The BS finds another two MSs as the RSs; one, RS_2, is in the region B_1 and the other, RS_1, is in microcell *A*. For UL transmission, a three- hop call requires two UL CHs from microcell *B* and one UL CH from microcell *A*. The CHs are used for the transmission from MS_2 to RS_2, from RS_2 to RS_1 and RS_1 to the BS, respectively. For DL transmission, a three-hop call requires two DL CHs from microcell *A* and one DL CH from microcell *B*, which are for the transmission from the BS to RS_1, from RS_1 to RS_2 and from RS_2 to MS_3, respectively. A three- hop call is accepted if all the following conditions satisfy: (i) microcell *A* finds one free UL CH; (ii) microcell *B* finds two free UL CHs; (iii) microcell *A* finds two free DL CHs; and (iv) microcell *B* finds one free DL CH. Otherwise, it is blocked.

Next, the channel assignment is based on the information provided in the Interference Information Tables (IITs). Two global IITs, which store, update and process the channel status, are located in the mobile switching center (MSC) for uplink (UL) and downlink (DL). We assume that every DIP is able to access to the global IITs through its corresponding BS using a separate control CH. As shown in Fig. 2, a 49- microcell network model with 7 macro cells is considered. The UL IIT contains information of the entire *N* UL CHs, as shown in Table I. The IIT for DL is similar and not shown here. Another table, the Interference Constraint Table (ICT), as shown in Table II, contains the information of interfering cells (including the central microcell) for each microcell. ICT is also located in the MSC.

Different reuse factor, N_r, can be used in ICT as shown in Table II. For example, for N_r =3, the number of interfering cells is six and they are located in the first surrounding tier. Refer to Fig. 2 and Table II; the interfering cells for cell 24 are cells 17, 18, 23, 25, 30, 31. There is no special sequence for the interfering cells in Table II, which is purely based on the cell configuration in Fig. 2. By using the appropriate set of interfering cell information in ICT, we can apply mDCA with any reuse factor N_r.

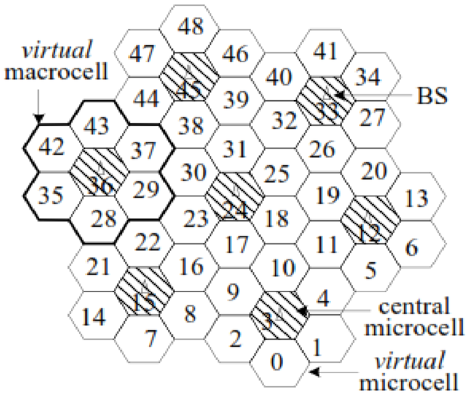

Figure 2. The simulated 49-cell network.

The content of an IIT is described as follows. For clarity, we denote the set of interfering cells of any microcell *A* as *I*(*A*), which varies with N_r. The information of *I*(*A*) can be obtained from the ICT.

TABLE - I
Interference Information Table

Cells	Channels				
	1	**2**	**3**	**…**	**N**
0	L	L	2L	…	L
1		2L	U_{22}	…	U_{33}
2	L	L	2L	…	2L
…	…	…	…	…	…
48	U_{22}	L	U_{33}	…	2L

TABLE – II
Interference Constraints Table

Cell	Central Microcell	Interfering Cells with Different N_r								
		N_r=7								
		N_r=4							/	/
		N_r=3					/	/	/	/
		1	2	3	...	6	...	12	...	18
0	3	40	46	2	...	41	...	39	...	34
1	3	41	0	3	...	35	...	40	...	28
...	...	...	...	...	...	...	...	...	...	...
24	24	17	18	23	...	31	...	19	...	26
...	...	...	...	...	...	...	...	...	...	...
48	45	45	47	7	...	46	...	44	...	40

1) Used Channels: A letter ’$U_{11/22/33}$’ in the (microcell *A*, CH *j*) box indicates that CH *j* is a used CH in microcell *A*;
’U_{11}’ indicates the first-hop CH; ’U_{22}’ indicates the second- hop CH and ’U_{33}’ indicates the third-hop CH. The first-hop CH means the CH used between the BS and a MS in the central microcell. The second-hop CH means the CH used between the MS in the central microcell and the MS in the inner half region of a *virtual* microcell. The third-hop CH means the CH used between the MS in the inner half region of a *virtual* microcell and the MS in the outer half region of a *virtual* microcell.

2) Locked Channel: A letter ’L’ in (microcell *A*, CH *j*) box indicates that one cell in the set *I*(*A*), say microcell *X*, is using CH *j*. We refer microcell *X* as a locking cell and microcell *A* as a locked cell for CH *j*.

3) Free Channels: An empty (microcell *A*, CH *j*) box indicates that CH *j* is a free CH for microcell *A*.

Then, the channel searching strategy is described as follows. When a new call arrives, mDCA always searches for a CH from a lower-numbered CH to a higher-numbered CH in its central microcell from the UL IIT. Once a free CH is found, it is assigned to the first-hop link. Similarly, mDCA attempts to find the UL CHs for second- or third-hop links for that call in its *virtual* microcell from the UL IIT if it is a multihop call. For example, for a two-hop call from MS_2 in Fig. 1, mDCA finds the first-hop UL CH, *j*, in microcell *A* from Table I. Based on the ICT in Table II, CH *j* cannot be reused in microcell *B*. Then, mDCA searches for the second-hop UL CH (not CH *j*) in microcell B from Table I. The searching procedure is similar for the DL.

Finally, the channel status for a CH *j* in the UL (DL) IIT is updated when it is assigned to a new call or released upon a completed call. For channel assignment, after the UL (DL) CH *j* in microcell *A* is assigned to a call, the MSC will (i) insert a letter ’$U_{11/22/33}$’ with the corresponding subscript in the (*A*, *j*) entry box of the UL (DL) IIT; (ii) update the entry boxes for (*I*(*A*), *j*) by increasing the ’L’ value in the UL (DL) IIT. For channel releasing, after the UL (DL) CH *j* in microcell *A* is released, the MSC will (i) empty the entry box for (*A*, *j*) of the UL (DL) IIT; (ii) update the entry boxes for (*I*(*A*), *j*) by reducing the ’L’ value in the UL (DL) IIT.

4. Simulation Results

The simulated network is shown in Fig. 2. Wrap-around technique is used to avoid the edge effect. We consider a total of *N*=140 system CHs and simply use N_r=4 and N_r=7 to illustrate the performance of mDCA. Uniform traffic is assumed and calls arrive according to a Poisson process with a call arrival rate per macrocell area uniformly. Call durations are exponentially distributed with a mean of $1/\mu$. The offered traffic to a macrocell is given by $\rho = \lambda/\mu$. Each simulation runs until 100 million calls are processed. For the conventional FCA in SCNs, the results are obtained from Erlang B formula be assigning each microcell N/Nr channels.

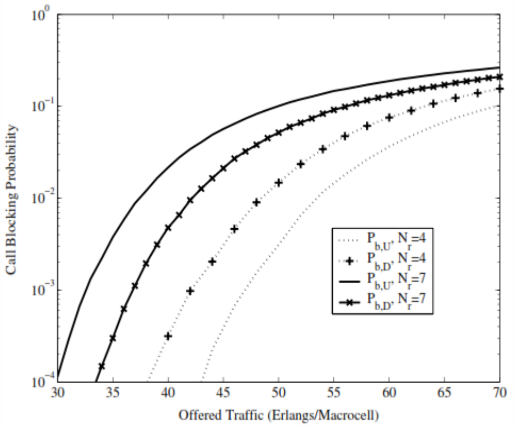

Figure 3. Capacity for uplink and downlink for cMCN using mDCA.

Figure 3 shows Uplink / Downlink blocking probability P_{b-u} / P_{b-d}, for the proposed scheme with Nr=4 and Nr=7. The P_{b-d} is lower than P_{b-u} for Nr=7 while P_{b-d} is higher than P_{b-u} for Nr=4.This is due to asymmetric nature of channel assignment. For 2 hop or 3 hop calls, more call are utilised in central cell for down link transmission than for Uplink. Consequently, for N_r =7, more DL CHs can be reused with minimum reuse distance and thus, $P_{b,D}$ is lower than $P_{b,U}$. On the other hand, for two-hop or three-hop calls, more CHs are used in the *virtual* microcell for UL transmission than DL transmission. For N_r =4, those UL CHs used in *virtual* microcells are better packed than DL CHs used in central microcells. Thus more UL channels can be used with minimum reuse distance, and P_{b-u} is lower than $P_{b,D}$ with Nr=4.

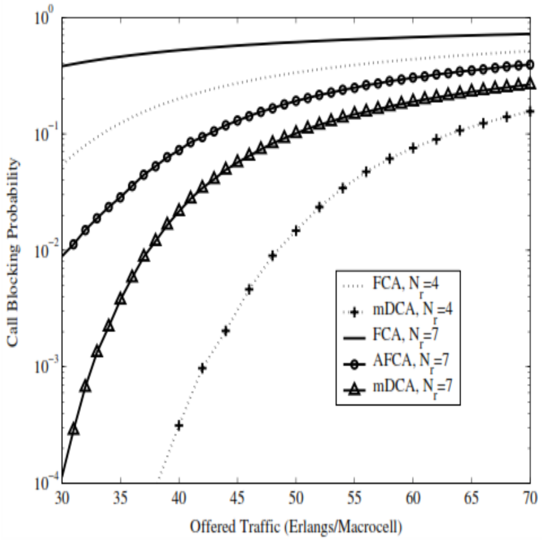

Figure 4. Capacity comparison at *N*=140.

Figure 4 shows Average Blocking Probability for MDCA, and the conventional FCA in SCN for N_r =4 and N_r =7. The capacity improvements at P_b =1% for mDCA over conventional FCA are 96% and 210% for N_r =4 and N_r =7, respectively. Furthermore, with N_r =7, mDCA also outperforms AFCA with a capacity improvement factor of 22%. In conclusion, our proposed mDCA can be applied for any reuse factor by adapting the ICT and it outperforms the conventional FCA and the AFCA for cMCN substantially.

5. Conclusion

In cellular mobile communication system channel demand has both spatial and temporal variation. It is seen that during busy office hours (temporal) or in some part of the city (spatial) the channel allocation changes very frequently and rapidly. Thus an efficient channel allocation algorithm is very complex and complicated task. Dynamically changing the channels allocated to different cells enable the system to adapt to temporal and spatial distribution of channel demand. The proposed technique which is based on dynamic channel allocation will show remarkable achievement in terms of i) blocking probability ii) forced termination probability. We shall improve the technique in future that will outperform the existing technique both during peak hours and in congested part of the city, reducing the message complexity and channel acquisition delay.

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