Access Point Contention-based Distributed Scheduling in Densely Deployed Network Environments

Sung-Guk Yoon · Jeongkyun Yun · Jonghun Han · Saewoong Bahk

With increasing demands for high data rate services, femtocell networks or small cell sized WLANs have emerged as promising technologies. Since each femtocell network or WLAN consists of uncoordinated subnetworks independently, interference from others can degrade overall network capacity severely. In this paper, we address the interference problem between uncoordinated Access Points (APs) and propose a distributed AP scheduling scheme in a densely deployed femtocell network. To mitigate the interference problem, our proposal focuses on sharing the time resource through AP contention while previous researches have focused on adjusting power and frequency resources. According to the contention result, a winning AP is determined to use the next time frame solely. To operate in a fully distributed manner, our proposal needs help from Mobile Nodes (MNs) and requires a new synchronous frame structure which uses special common control channels. Simulation results show our proposed scheme doubles the network capacity compared to the legacy non-contending scheme.

Keywords: Interference management, Self-organizing networks, Femtocell, Contention based scheduling

I. INTRODUCTION

While the very beginning of wireless communication started with humble beginnings, by exchanging Morse codes, the upcoming fourth generation wireless technologies, for instance, IEEE 802.11n, 802.16 m and LTE-advanced, are expected to achieve the wireless capacity of about 1 Gbps. The wireless capacity has doubled every 30 months over the last 100 years [1]. The core factor of the increase in capacity has been the reduction a cell size, which contributed to an increase of 1,600 times, While Advanced Physical (PHY) and Media Access Control (MAC) layer technologies, such as modulation and resource management schemes, contributed to only a 25 times increase in performance.

The important advantage of reducing the cell size is that the receiver is able to get data packets with high Signal to Noise Ratio (SNR). Conventional wireless networks take advantage of this smaller cell size to increase the wireless capacity since receivers can get the desired signal with higher strength. However, the gain obtained from the smaller cell size could get compromised by the heavy interference that closes proximity cause between neighboring cells. This means that network systems are becoming interference dominated, thus a more important metric for network capacity is the Signal to Interference-plus-Noise Ratio (SINR) rather than SNR. Therefore, each transmitter in a cell cannot use full power to care about neighboring cells. That is, reducing the cell size is not that effective in increasing the network capacity.

Recently another user establishing device, called Femtocell Access Point (FAP) [2], [3], has shown up in the market. FAPs work similarly to cellular Base stations (BSs)[1], but each FAP covers a small indoor area. Because

논문번호: TR11-021, 논문접수일자:2011.03.03, 논문수정일자:2011.08.02, 논문게재확정일자:2011.08.22
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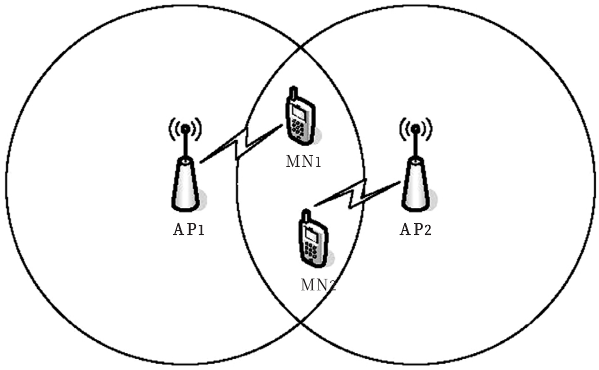

Figure 1. Example of Interference

of uncoordinated deploy of FAPs, an FAP coverage can overlap with macro BSs and other FAPs, so that interference is a key issue in femtocell networks [4]. An FAP uses a wired backbone connection to communicate with the cellular core network. Since WLAN APs already suffer from severe interference from neighboring APs today, it is not hard to imagine that FAPs will have the same or even greater interference problems down the road.

In reducing the cell size, we have to balance both economic as well as technical issues. Since a smaller cell size implies that more BSs are needed to cover the same area, a service provider cannot help but increase capital expenditure (CAPEX) and operational expenditure (OPEX). For the CAPEX viewpoint, more BSs lead to fewer prices per BS due to economies of scale. However, the OPEX will increase in proportion to the number of BSs from the perspective of conventional network management. The key technical solution to the problem of reducing the OPEX is to have a Self-Organizing Network (SON) technology. It enables each BS to run in a plug-and-play manner and the network to be organized autonomously without having an explicit coordinator.

The SON needs to be harmonized with the interference mitigation to maximize the efficiency. Conventional interference mitigation algorithms control frequency and/or power resources, and assume that all BSs are intimately connected to each other [5]. This means that the concepts of tightly coupled networks and SON technology contradict each other. There are two types of interference issues in the femtocell network: between macrocell and femtocell; and between the femtocell themselves. For the first interference problem, there have been certain approaches proposed to solve this problem by controlling the transmission power [7]~[9]. For the second problem, Li et al. [10] have proposed a fractional frequency allocation scheme between FAPs through sensing each other's interference level. Their solution relies on a strong assumption that each FAP fully understands the interference condition exactly. Stolyar et al. [11] proposed a dynamic FFR method for interference mitigation. However, in a densely deployed network, the interference cannot be sufficiently mitigated by only frequency and power planning.

The interference cannot be sufficiently mitigated by only frequency and power planning in a densely deployed network. To solve this severe interference problem, a technical report [6] from 3GPP proposed an interference reduction scheme by allocating a different frame access pattern to each FAP or macro-femto BSs in time domain, but each pattern should be allocated by a central controller. In this paper, we propose a distributed interference mitigation algorithm for a SON. Our proposed algorithm activates as many APs as possible, while keeping a certain interference level on each AP. To implement this in a fully distributed manner, Mobile Nodes (MNs) should report the result of AP contention to the APs through a common control channel specified in our proposed frame structure.

The paper is organized as follows. Section II presents our proposed frame structure and AP contention based scheduling algorithm. We examine the performance of our proposed scheme through analysis and simulation in Sections III and IV, respectively. Conclusion is in Section V.

1) In this paper, we use the terms AP and FAP and BS interchangeably.

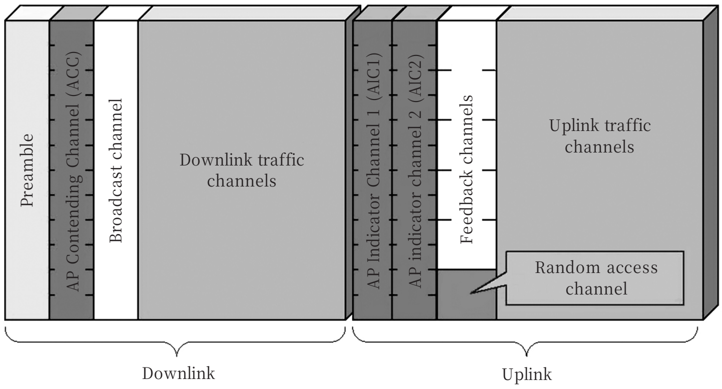

Figure 2. Contention enabling synchronous frame structure for TDD OFDMA system

II. PROPOSED CHANNEL ACCESS METHOD

For clarity of exposition, we assume that all APs in the interference dominant network use only single frequency band. Although our proposed scheme can easily adopt other multiple access and duplex schemes such as a Frequency-Division Duplex (FDD) based OFDMA or Code Division Multiple Access (CDMA) system, we assume that the network uses a Time-Division Duplex (TDD) based orthogonal Frequency Division Multiple Access (OFDMA) system, and that frames transferred among APs are synchronized.

As shown in Figure 1, AP_1 and AP_2 try to send data to MN_1 and MN_2 simultaneously, resulting in an interference domain. In such domain[2)], our interference mitigation algorithm activates only one AP among APs in a distributed manner. Legacy schemes resolve by using a low Modulation and coding Scheme (MCS) at APs to overcome the interference from one another. Other schemes reduce the interference by letting APs transmit data in turn, i.e., AP_1 and AP_2 use different time-frames.

As time scheduling algorithm plays a significant role in the understanding of our proposed scheme so we briefly illustrate its impact on network capacity. As mentioned above, with reference to Figure 1, the legacy scheme consumes the entire time-frame under low SINR when the two APs work simultaneously. In contrast, application of time scheduling scheme allows use of half of the time-frame, though each AP is under a high SINR. From the Shannon capacity formula, which is given as $\log_2(1+SINR)$, we obtain the capacity of each scheme for an AP as following:

$$C = \begin{cases} \log_2(1+SINR_{int}) & \textit{for legacy scheme}, \\ 1/2\,\log_2(1+SINR_{clr}), & \textit{for time scheduling scheme}, \end{cases}$$

where $SINR_{int}$ and $SINR_{clr}$ represent the SINRs with and without interference, respectively. In a high interference area, the $SINR_{int}$ could be almost equal to 1, so the capacity is 1 bit/sec/Hz. If $SINR_{clr}$ is larger than 3, which is 4.8 dB, the network capacity with the time division AP scheduling scheme is larger than without it.

In a densely deployed network, $SINR_{clr}$ is generally substantially larger than three times $SINR_{int}$ since each MN is usually associated with the closest AP. Therefore, the AP time scheduling scheme logically outperforms the legacy scheme.

1. Contention enabling frame structure

In order to handle the interference problem in a distributed manner, we first consider a contention enabling synchronous frame structure. Figure 2 depicts an example of our proposed structure. This is a simple modification of a traditional TDD and OFDMA based cellular frame structure. The only difference from the legacy structure is that it additionally uses one AP Contending Channel (ACC) and two AP Indicator Channels (AICs) for downlink and uplink, respectively.

ACC and AIC use a small number of OFDMA symbols. In this example, each of ACC and AIC uses one resource block which consists of one symbol time and

2) We define the interference domain in Section II-B.

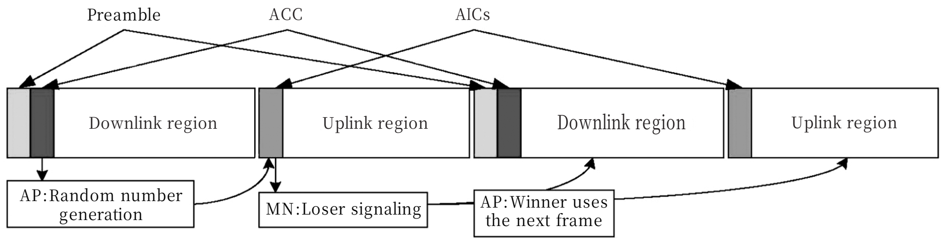

Figure 3. Frame allocation using ACC/AICs pair contention

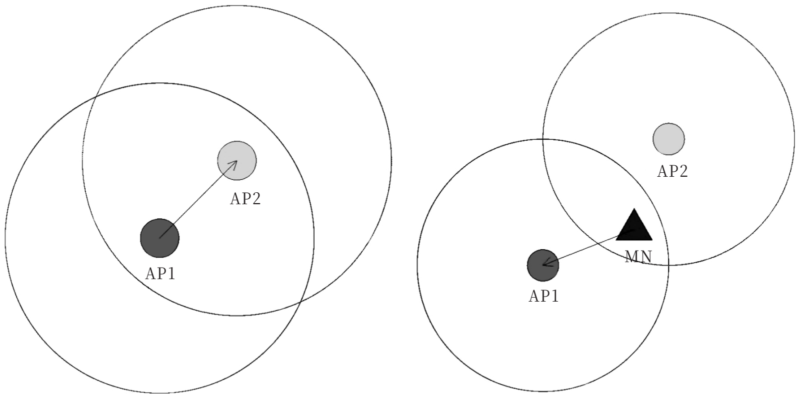

Figure 4. Definition of 'neighbor APs.' In left figure, although the two APs can see each other but share no MN, they are not 'neighbor APs.' However, in right figure, since the two APs share a common MN, they are 'neighbor APs.'

several sub-channels. Every ACC has corresponding AICs (AIC1 and AIC2). During the initialization procedure, each AP obtains its own ACC/AICs pair which does not overlap with those of neighboring APs. Further, each AP transmits a random number for contention through its own ACC. AICs carry binary information only, so one bit of information is enough for each AIC, i.e., the OFDM symbol of busy or idle. Because of the use of one bit signaling, there is no collision in AIC. We represent at least one busy signal and no busy signal as '1' and '0', respectively. AIC1 and AIC2 send the result of the contention and collision, respectively. The values '0' and '1' received from AIC1 mean that the AP which sent a random number through the ACC won and lost the contention, respectively. Similarly, '0' and '1' from AIC2 indicate that ACC data received without and with collision, respectively.

2. Notations

We now define some notation to explain the detailed algorithm for our proposed scheme.

- A_i: Access point *i*.
- M_{ij}: Mobile node *j* associated with A_i.
- $C(A_i)$: Set of MNs that are in the coverage of A_i.
- $C(M_{ij}) = \{A_k \mid M_{ij} \in C(A_k), \forall k\}$
- $NB(A_i)$: Set of neighbor APs that share at least one MN with A_i, i.e., the interference domain of A_i.
- S_f: Current frame sequence number.
- N_{ch}: Total number of ACC/AICs pairs.
- c_i: ACC/AICs pair number obtained by A_i.
- W: Contention window size.
- r_i: Random number used by A_i during contention.

3. Contention for channel access

Our aim is to enable an AP to use the shared medium exclusively. That is, A_i should be the only active AP among $A_i \cup NB(A_i)$ at a specific time frame (both downlink and uplink). To access the channel, each AP first contends with neighboring APs. When an AP wins the channel contention, it can use the next time frame exclusively and schedule data transmissions for MNs in its own domain as

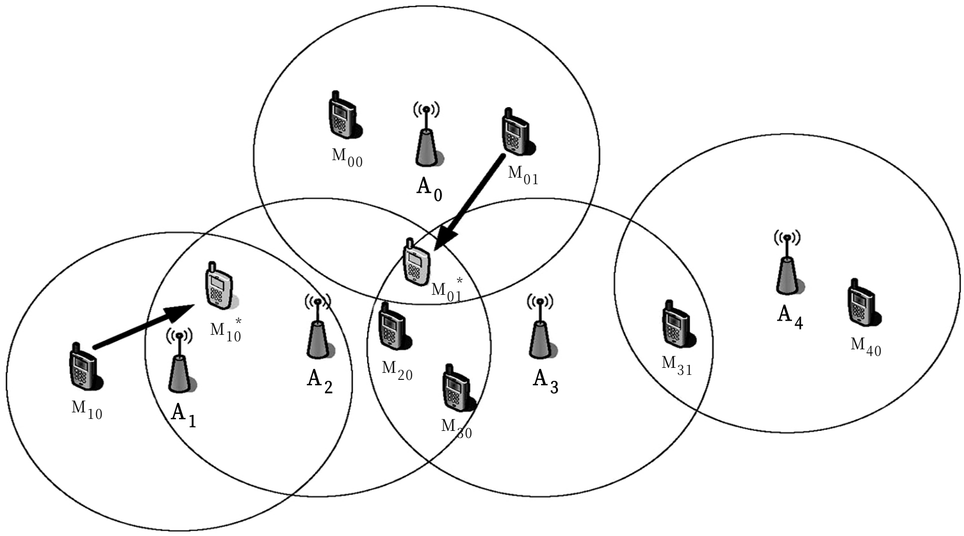

Figure 5. Example topology

depicted in Figure 3.

According to our scheme, the definition of a 'neighbor APs' is not one-hop connected APs but those APs that share at least one MN in their shared coverage as explained in Figure 4 (RHS). Therefore, in Figure 4 (LHS), the APs are not neighbors to each other unless an MN appears in the shared area.[3)]

The contention method works as follows: In the first frame, each AP A_i selects a random number r_i within the contention window [0,W), and broadcasts r_i through its own ACC c_i. Each MN M_{ij} hears all the random numbers broadcasted by their neighbor APs C(M_{ij}), and decides a winner, i.e., the smallest r_i. When a winner is decided, every MN that hears ACC replies via each corresponding AIC1 of all the losing APs. Since these AIC responses are signals i.e., busy or idle, and do not have any information, so there is no collision problem in AIC responses.

In such scenario, there can be two types of collision: random number collision which occurs when more than one AP chooses the same smallest number; and ACC collision which occurs when more than one AP chooses the same ACC/AICs pair. For the random number collision, the corresponding MNs break the tie as follows:

According to the current frame sequence number S_f, if is S_f odd (or even), our algorithm select an AP that uses the ACC with the highest (or lowest) c_i as the winner.

For the ACC collision problem, the corresponding MNs in the shared area recognize the collision, and are responsible for reporting it to the APs involved. To resolve this collision, these APs must select another ACC/AICs pair randomly until the selected channel pair is clear. The detailed collision resolution mechanism is described in the following sub-section.

4. Procedures for ACC/AICs pair allocation

Each AP should have its own non-overlapping ACC/AICs pair to contend with other APs. To obtain an ACC/AICs pair, a newly joining AP A_i listens to all the ACCs for a defined time period to tabulate information of busy ACC/AICs pairs. Later, A_i randomly selects one idle ACC/AICs pair among the idle ones, and uses it for contention. An ACC collision may still occur if a neighbor AP chooses the same ACC/AICs pair as being used by neighbor or a new MN appears in the shared area while two APs are using the same ACC/AICs pair.

For instance, in Figure 4 (LHS) , if the two APs share no MNs, they can use the same ACC/AICs pair without experiencing ACC collision, but in the case of Figure 4 (RHS), the two APs need to use different ACC/AICs pair. If the two APs use the same ACC, M_{ij} can hear neither of the two APs. M_{ij} informs this ACC collision to the APs by transmitting a '1' through the corresponding AIC2. All APs using this ACC hear the message to recognize whether they were involved in a collision or not. If the AP is informed of

3) We assume that all APs or BSs are synchronized as in cellular networks.

Table 1. Contention Example

First frame

AP id	ACC		AIC1 (win/lose)	AIC2 (collision)
	Sub-channel #	Random #		
0	2	5		
1	4	12		
2	4	6		
3	5	10	M_{20}, M_{30}	M_{31}
4	5	2		M_{31}
* Event: M_{10} moves to M^*_{10} → A_1 and A_2 become neighbors.				

Second frame

AP id	ACC		AIC1 (win/lose)	AIC2 (collision)
	Sub-channel #	Random #		
√0	2	3		
√1	4	1		M_{10}
√2	4	11	M_{20}, M_{30}	M_{10}
3	3	7		
4	8	14	M_{31}	
* Event: M_{01} moves to M^*_{01} → A_0, A_2 and A_3 become neighbors.				

Third frame

AP id	ACC		AIC1 (win/lose)	AIC2 (collision)
	Sub-channel #	Random #		
√0	2	10	M_{01}	
1	5	3		
2	7	4	M_{01}, M_{20}, M_{30}	
√3	3	1	M_{31}	
4	8	1		

Fourth frame

AP id	ACC		AIC1 (win/lose)	AIC2 (collision)
	Sub-channel #	Random #		
0	2	5	M_{01}	
√1	5	1		
2	7	2	M_{10}	
3	3	4	M_{01}, M_{20}, M_{30}	
√4	8	6	M_{31}	

Fifth frame

AP id	ACC		AIC1 (win/lose)	AIC2 (collision)
	Sub-channel #	Random #		
0	2	3		
√1	5	5		
2	7	10	M_{01}, M_{10},M_{20}, M_{30}	
3	3	8	M_{01}, M_{31}	
4	8	5		

an ACC collision, it randomly selects another ACC/AICs pair among the idle channel pairs.

5. Operation example

In this section, we explain our proposed scheme through an example as shown in Figure 5. Let there be five APs and seven MNs within the network, and each A_i has one or two serving MNs (M_{ij}) in its service region. We set $N_{ch} = 10$ and $W = 16$. The entire scenario is presented in Table 1.

At first, M_{10} and M_{01} are located out of the shared area. This implies A_0 and A_1 do not interfere with each other even though A_2 is in the range of A_1. However, when M_{10} moves to position M^*_{10}, A_1 and A_2 become interfering neighbors. Similarly, when M_{01} moves to position M^*_{10}, A_0, A_2, and A_3 become interfering neighbors to each other.

When interference scenario initiates, each AP randomly chooses one ACC/AICs pair out of N_{ch}. Therby, let APs A_0 through A_4 randomly pick the ACC/AICs pair c_i of 2, 4, 4, 5, and 5, respectively. In addition, each APi picks a random contention number r_i in contention window [0,W). Let these selected r_i's be 5, 12, 6, 10, and 2, respectively at the first frame, and let each APi transmits r_i via its own ACC c_i. Since A_1 and A_2 initially share no MN, they do not suffer from ACC collision. In addition, as A_1 and A_2 do not need to contend so A_1 and A_2 can serve their MNs, i.e., M_{10} and M_{20}, simultaneously without suffering from interference. However, since MN M_{31} is in the shared area of A_3 and A_4, A_4's communication interferes with the communication between A_3 and M_{31}. This implies that A_3 and A_4 should now contend for the frame to avoid simultaneous activation. In this example, since A_3 and A_4 selected the same ACC, i.e., $c_3 = c_4 = 5$, by chance, M_{31} would be unable to decode the received random numbers r_3 and r_4 transmitted by A_3 and A_4, respectively. In such a case, MN M_{31} would inform such ACC collision on ACC 5 via AIC2. After receiving collision message, A_3 and A_4 randomly choose another ACC/AICs pairs again among the idle channel pairs.

In another case of two MNs (M_{20} and M_{30}) in the shared area of A_2 and A_3, the APs should have different ACC/AICs pairs and contend with each other to use a time frame exclusively. In this case, if A_2 and A_3 select different ACC/AICs pairs then M_{20} and M_{30} can decode their random numbers r_2 and r_3 broadcasted via c_2 and c_3, respectively. Since A_3 chooses a larger number compared to A_2, M_{20} and M_{30} inform A_3 that they have lost the contention. As a result, in the second frame, A_0, A_1, and A_2 are activated. In Table 1, we check the active APs with check marks (√) beside each AP id.

Further, we take a scenario at the end of the first frame where M_{10} moves to M^*_{10}. This implies that now A_1 and A_2 become neighbors of each other. In the second frame, A_1 and A_2 collide with each other in ACC 4, and M_{10} informs the APs of this ACC collision via the AIC2. Then they change the channel pair for next contention. In this frame, A_3 and A_4 choose different ACCs, i.e., $c_3 = 3$ and $c_4 = 8$, because of the ACC collision in the first frame, and use c_3 and c_4 for contention, respectively. Applying the same rules, as described above, A_3 wins this contention and A_0 and A_3 use the next frame according to our algorithmic policy.

Further, in the third frame, there is no ACC collision, that is, each A_i can contend with $NB(A_i)$. Since M_{01} moves to M^*_{01} after the second frame, M_{01} makes A_0, A_2, and A_3 neighbors of each other. In this frame, A_3 wins the contention among the three APs in the set $C(M_{01})$. M_{01} informs A_0 and A_2 that they have lost the contention through the AIC1s (i.e., $c_0 = 2$ and $c_2 = 7$). However, since A_3 has lost the contention with A_4, A_3 also receives a loss signal from M_{31}. I t is note-worthy that A_3 and A_4 break the tie using the tie-breaking rule, that is, the lowest channel numbered AP wins at an odd frame sequence number. The active APs in the fourth frame are now A_1 and A_4.

In the fourth frame, we show worst-case scenario i.e. A_0, A_2, A_3 and A_4 are beaten by their neighbor APs. This would imply that only A_1 is activated for the fifth frame. To overcome worst-case scenario inefficiency, we propose an extension called multi-frame contention in the next sub-section.

6. Multi-frame contention

To further extend and improve channel utilization, we propose a multi-frame contention mechanism that uses the multi round contention to select multiple APs eligible to use next multiple frames. This results in a greater number of activated APs.

We combine R frames into one super frame which consists of R-rounds of the contention mechanism.[4)] After going through an R-round contention, the winning multiple APs can exclusively use the next super frame of

4) Each frame indicates a round.

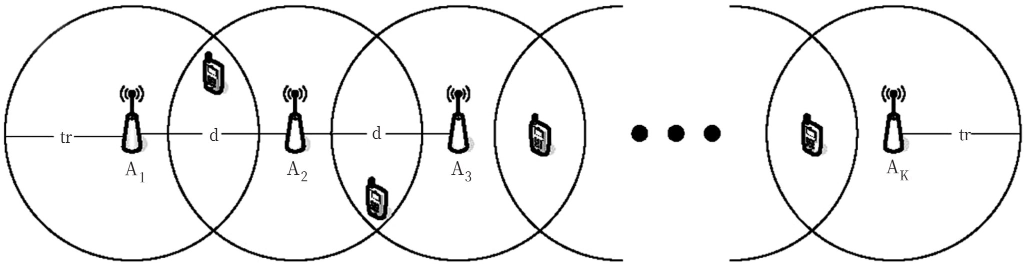

Figure 6. Simple chain topology with K APs. t_r and d denote the transmission range of AP and the distance between two neighboring APs

R frames. Each winner AP i uses '-1' as the r_i for next contention throughout the same super frame to keep itself as the winner by the end of the super frame. The lost APs get more chances to win during the same super frame.

For instance, in the fourth frame case discussed in the previous example, we assume that the fourth and fifth frames are for one super frame ($R = 2$). Since A_1 won the previous frame, it sets $r_1 = -1$ in the fifth frame while the other APs choose random numbers as shown in Table 1. As a result, A_0, A_1 and A_4 can now be activated during the sixth and seventh frames that are the next super frame. Following this way, the multi-frame contention mechanism can improve the channel utilization.

III. PERFORMANCE ANALYSIS

1. Channel utilization analysis

In this section, we analyze the channel utilization when using our proposed AP contention based scheduling scheme for a simple chain topology. We define the channel utilization U as the ratio of the number of active APs to the total number of APs in the network.

We consider a simply connected chain topology as shown in Figure 6. Simple chain topology with K APs. t_r and d denote the transmission range of AP and the distance between two neighboring APs.where the chain length[5)] is K. Here, 'connected' means that every AP must contend with its nearby APs. That is, neighboring APs share at least one MN. Let t_r and d be the transmission range of an AP and the distance between two neighboring APs, respectively. For the considered topology, we obtain the following Lemma 1.

- **Lemma 1**. *In the simply connected chain topology with* $t_r < d \leq 2t_r$, *the channel utilization is given by*

$$U = \begin{cases} 1, & \text{when } K = 1, \\ \dfrac{K+1}{3K} - \dfrac{K-2}{12KW^2}, & \text{when } K \geq 2. \end{cases} \quad (1)$$

Proof: Let us denote the activation probability of A_i as P_i. Then, we calculate P_i as follows. For $K = 1$, the channel utilization is obviously one, so we focus on the case when $K \geq 2$.

① For $i = 1$ or K:
Since the tie breaking rule selects one AP almost randomly, we first calculate the probability for each tie braking case and average the results.

$$\begin{cases} \Pr\{r_1 \leq r_2\} = 1/W \sum_{j=0}^{W-1} \dfrac{W-j}{W} = \dfrac{W+1}{2W}, \\ \quad \textit{when the tie makes } A_1 \textit{ win}, \\ \Pr\{r_1 < r_2\} = 1/W \sum_{j=0}^{W-1} \dfrac{W-1-j}{W} = \dfrac{W-1}{2W}, \\ \quad \textit{when the tie makes } A_1 \textit{ lose}. \end{cases}$$

Therefore, we have

$$P_i = \frac{1}{2} \cdot \frac{W+1}{2W} + \frac{1}{2} \cdot \frac{W-1}{2W} = \frac{1}{2} \quad (2)$$

5) The number of APs in the connected chain.

② We now have four tie breaking cases. For each case, we obtain the following.

$$\begin{cases} \Pr\{r_i < r_{i-1}, r_i \le r_{i+1}\} = 1/W \sum_{j=0}^{W-1} \left(\frac{W-1-j}{W} \cdot \frac{W-j}{W}\right) \\ \qquad = \frac{(W-1)(W+1)}{3W^2}, \\ \Pr\{r_i < r_{i-1}, r_i < r_{i+1}\} = 1/W \sum_{j=0}^{W-1} \left(\frac{W-1-j}{W}\right)^2 \\ \qquad = \frac{(W-1)(2W-1)}{6W^2}, \\ \Pr\{r_i \le r_{i-1}, r_i \le r_{i+1}\} = 1/W \sum_{j=0}^{W-1} \left(\frac{W-j}{W}\right)^2 \\ \qquad = \frac{(W+1)(2W+1)}{6W^2}, \\ \Pr\{r_i \le r_{i-1}, r_i < r_{i+1}\} = \frac{(W-1)(W+1)}{3W^2}. \end{cases}$$

Therefore, we have

$$P_i = 1/4\left(2 \cdot \frac{(W-1)(W+1)}{3W^2} + \frac{(W-1)(2W-1)}{6W^2} + \frac{(W+1)(2W+1)}{6W^2}\right) = \frac{4W^2-1}{12W^2}. \quad (3)$$

From (2) and (3), we can calculate the average channel utilization U as

$$U = \frac{1}{K}\sum_{i=1}^{K} P_i = \frac{1}{K}\left(2 \cdot \frac{1}{2} + (K-2) \cdot \frac{4W^2-1}{12W^2}\right) = \frac{K+1}{3K} - \frac{K-2}{12KW^2}. \qquad \blacksquare$$

When K is larger than one, the second term in (1) can be ignored if W is large enough. For instance, if $W = 64$ and $K = 20$ which is similar with our simulation environment, we can ignore the second term. Therefore, we approximate the utilization U as follows

$$U \approx \frac{K+1}{3K} \quad (4)$$

2. Overhead analysis for using ACC/AICs pairs

In our AP contention scheme, the system must use two special common control channels (ACC and AIC), which convey the contention information. Since these additional channels can be viewed as overhead, we now calculate the size of the overhead when Mobile WiMAX specification [12] is applied.

For the downlink case, there are 720 data sub-carriers out of 1024 total sub-carriers per OFDMA symbol[6]. The data sub-carriers are divided into 30 sub-channels, and one sub-channel corresponds to the downlink resource allocation unit. That is, each sub-channel has 24 sub-carriers per symbol. We assume that one ACC consumes one sub-channel in one symbol. For the AP contention, the ACC information must successfully reach all MNs within the transmission range of each AP. The Frame Control Header (FCH[7]) is also very important, and it uses not only low modulation (QPSK) and coding rate (1/2) but also four repetition codes to protect the information. Assuming that the ACC information also uses the same repetition, modulation, and coding with FCH; one ACC can carry six bits[8]. Note that this is conservative usage since an FAP's transmission range is much smaller than that of macro BS, and the femtocell environment is normally indoor. Through the six bits, each AP can select a random number in [0, 64) for contention; it is large enough to keep the probability of random number collision between APs very small.

The resource unit of the uplink is a tile which consists of three OFDMA symbol and four sub-carriers. To ensure that the AIC is robust enough, we use three tiles which are the same number of tiles on one ACK transmission. Note that using three tiles for one AIC is also conservative usage because of the same reason as in the downlink case.

We now can calculate the additional overhead of the ACC/AICs pairs under the above two assumptions.

6) We assume that the system uses 10 Mhz bandwidth and OFDMA/TDD.
7) FCH is header for the MAP message.
8) Through four repetition, 1/2-convolution coding, and QPSK modulation; to carry six bits, it needs 24 sub-carriers (4× 2× 1/2× 6=24).
9) Downlink control channels: FCH, DL-MAP, UL-MAP; uplink control channels: CQICH, ACK, Ranging channel.

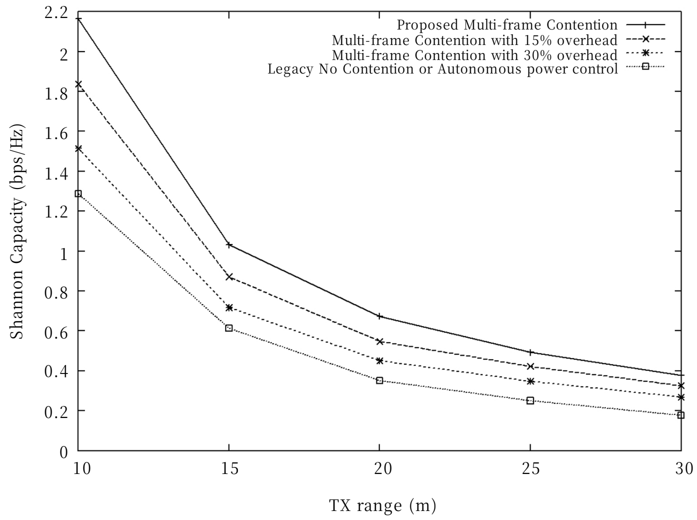

Figure 7. Shannon capacity (spectral efficiency)

Excluding the original overhead[9)], a frame of Mobile WiMAX normally has 26 OFDMA symbols for downlink and 840 tiles for uplink. There are two AICs corresponding to one ACC, which are AIC1 and AIC2. Assuming that n ACC/AICs pairs are added using our proposed frame structure, the portions of the additional overhead are $24n/26\times840$ and $6n/840$ for downlink and uplink, respectively. In the case of 20 ACC/AICs pairs, the additional overhead is 2.56% and 14.3% for downlink and uplink, respectively.

IV. SIMULATION RESULTS

In this section, we compare the performance of our AP contention based scheduling scheme with that of a legacy non-contention based scheme in terms of capacity and fairness for a densely deployed femtocell network.

1. Simulation settings

Each AP runs as a closed subscriber group, that is, an MN can only communicate with its associated AP although the signal strengths from some other APs are stronger. Our proposed scheme uses the multi-frame contention of $R = 3$. Through simulations, we found that $R = 3$ well balances between channel utilization and multi frame overhead. We consider a 10 by 10 grid topology, that is, there are 100 FAPs in the scenario. The distance between two neighboring APs and the transmission range of each AP is set to 10 meters. The channels have the path loss exponent of four. Then various transmission ranges are tried in simulations under the same fixed distance. When the transmission range increases, the interference level increases too. We do not consider shadow fading and short term fading. Maximum and minimum transmission powers of FAPs are 20 and 0 dBm, respectively [13]. The background noise power is defined as -64.5 dBm. MNs associated with an AP are uniformly distributed within its transmission range. We also let the interference range twice longer than the transmission range. Within an interference area, each MN suffers from interference and cannot decode interferers' frames correctly.

2. Spectral efficiency

We use the Shannon capacity equation $C = \log_2(1 + SINR)$ to get the spectral efficiency, where SINR is calculated from the distance between MN and AP. Figure 7 shows the spectral efficiencies of our proposed scheme and the legacy scheme. The results show that our proposed scheme doubles the legacy capacity. To use our proposed scheme, the frame structure adds some additional overhead, i.e., ACC/AICs pairs. 15% and 30% of overhead indicates that 15% and 30% of each frame are wasted for the multi-frame contention, respectively. Our proposed scheme even with a 30% overhead outperforms the legacy scheme.

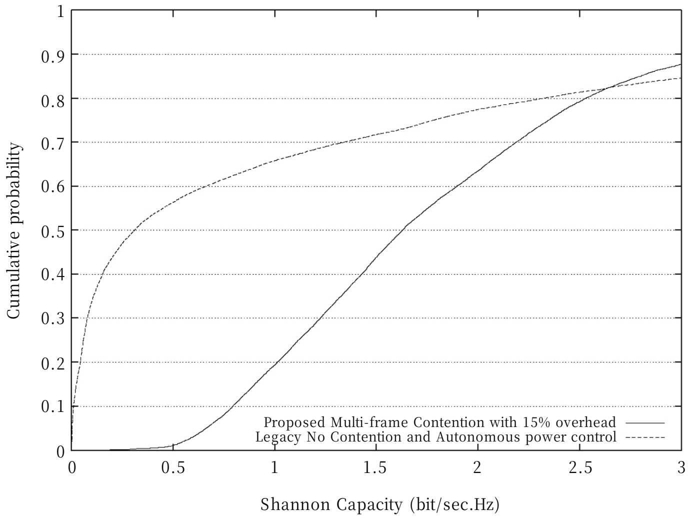

Figure 8. Cumulative distribution functions of the channel capacity(transmission range of 10m)

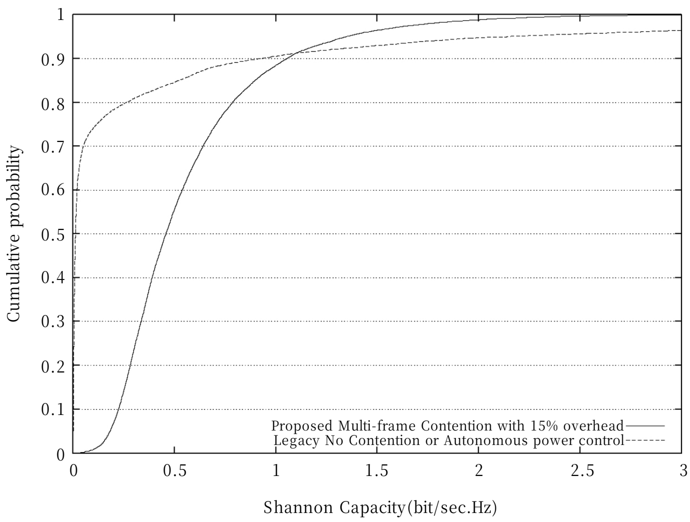

Figure 9. Cumulative distribution functions of the channel capacity(transmission range of 20 m)

3. CDF of spectral efficiency

The cumulative distribution functions (cdf) of spectral efficiency for the transmission ranges of 10 and 20 m are shown in Figure 8 and Figure 9. To cover the entire area, we uniformly placed 200 MNs. Each MN probes the SINR and calculates its Shannon capacity. We compared our proposed scheme with the autonomous power control scheme [14]. FAPs in the autonomous power control scheme adjust its power according to neighboring cell interference level, but it is the same as legacy no contention scheme in our simulation scenario, which means all the FAPs are using full power, since we assumed a very densely deployed network environment.

Figure 8 shows the cdf of spectral efficiency for the transmission range of 10 m. In this case, the number of MNs that experience small capacity is low since the MNs experience relatively low interference. In our proposed scheme, there are few MNs that have the capacity lower than 0.5 bps/Hz while there are more than 50 % such MNs in the legacy scheme.

In the case of 20-meter transmission range, the interference among MNs increases. As shown in Figure 9, the fraction of the low capacity MNs increases. In the legacy scheme, almost 70 % of the MNs cannot be served from their associated APs due to low SINRs. However, in our scheme, less than 10 % of the MNs have capacity lower than 0.25 bps/Hz. From these results, we can infer that our proposed scheme considerably reduces the outage ratio.

Note that to use our proposed contention scheme, each MN should use more power than that of legacy scheme to signal the win/lose and collision result to the FAPs. Recent study [15] measured and analyzed the power consumption of an MN in active (uplink and downlink) and sleep mode. Uplink transmission consumes about two times more power (0.25 W) than downlink transmission (0.1-0.15 W) and an idle mode MN consumes one tenth power (0.01 W) than that of downlink transmission. In addition, power consumption in idle listening (active mode without actual communication) has similar trend with power consumption in downlink mode. In our proposed scheme, MNs, with available data to communicate, only participate AIC signaling, and such signaling is one bit tone signal. Therefore, we expected that MNs in our proposed scheme consumes a little more power than that of legacy scheme.

V. CONCLUSION

Femtocell Access Points (FAPs) are expected to increase in home wireless networks, but the interference from and among femtocells will become a serious problem. In this paper, we proposed a novel AP contention based scheduling and frame structure that aims to mitigate distributively interference in a densely deployed wireless network. Our scheme chooses only one AP out of interfering APs to be active for each time frame, and allows the chosen AP to exclusively use the next time frame. This scheme reduces the overall network interference, thereby achieving significantly higher channel efficiency. The simulation and analytical results reveals that our AP contending scheme outperforms legacy non-contending scheme.

Since the current femtocell standard does not allow the modification of mobile devices, the interference problem is a very challenging one to solve. However, it is impossible to solve this problem without the help of the mobile devices since the main cause of interference comes from them. Accordingly, future standards should consider modifying mobile devices to mitigate the interference in some way. In such a case, the proposed AP contention based scheduling scheme could be a promising candidate solution.

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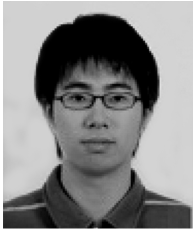

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