Interference-Controlled Load Sharing with Femtocell Relay for Macrocells in Cellular Networks

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***Abstract*—With the ever-growing demands of wireless communications, traffic load sharing is essentially important to provide consistent high quality of service (QoS). It is known that the QoS of mobile users is affected by the limited bandwidth in both wireless link and wired backhaul link beyond a base station (BS). Femtocell is a promising technology to bear part of the traffic load from the BS. Nonetheless, due to the small coverage and possible closed service policy, the number of users within a femtocell is so restricted that only a small part of the traffic load can be transferred via the femtocell. Hence, it has little help to relieve the regular BS traffic load. In this paper, we propose a femtocell relay method to increase the number of users using femtocell and further reduce the traffic load in macrocell. Specifically, femtocell users provide relay service for nearby users connected to the macrocell BS and get reward bonus through balancing the traffic load. The simulation results have shown that our method can effectively reduce the traffic load in the macrocell and improve the delivery performance for regular network traffic.**

***Index Terms*—Femtocell networks, relay service, load sharing, macrocells, PMIP.**

I. Introduction

In cellular networks, traffic load is a very important factor to provide quality of service (QoS) guarantee to mobile users. Compared with wired links, wireless links are more easily affected by environment variation so that the the bandwidth is not so stable as that of wired links. Meanwhile, the bandwidth of most backhauls for macrocell base stations (BS) is also limited, which is usually 3 to 8 Mbits/s per line [1]. Apparently, both the wireless link with the BS and the backhaul beyond the BS can be a bottleneck for the entire communication system. On the other hand, many popular applications, e.g., voice over IP (VoIP) and video telephony, may introduce a heavy traffic load for macrocells and affect the QoS to end users. Interestingly, as observed in the report from several large mobile operators, nearly 50% of mobile traffic occurs indoor (e.g., business buildings and personal residence) [2]. Exploiting this statistic observation, we can address the high traffic load problem using the femtocell technology.

Femtocells are kinds of low-power wireless access points that connect standard mobile devices to a mobile operator's network using residential digital subscriber line (DSL) or cable broadband connections [2]. Unlike IEEE 802.11-based WiFi access points (AP) working at unlicensed spectrum, femtocells operate in licensed spectrum which can provide better QoS guarantee than wireless local area networks (WLAN) because of less interference. Therefore, if femtocells can redirect part of traffic load to the IP backbone network, the traffic load in macrocells is decreased. However, because of the small coverage area and possible closed service policy that only allows authorized users to access, the number of femtocell users may not be very large to effectively balance the traffic load. It is known that most of femtocell access points (FAP) are deployed in an indoor environment [3], such as residential and enterprise hotspot settings. Because FAP works in the same spectrum range as macrocell BS, the transmit power of FAP is restricted in order to prevent interference with non-femtocell users [4]. Thus, compared to WiFi AP, the coverage area of FAP is much smaller, usually within 10 to 50 meters [5]. Therefore, the number of femtocell users is much less than that of WiFi users. Further, if femtocell owners choose a closed service policy, the amount of femtocell traffic is even lower [6].

In this paper, we study a femtocell relay method to balance the traffic load of the mobile operator's network by redirecting from a macrocell to overlaid femtocells. The essential idea is to have femtocell owners provide relay service for nearby users who are outside of femtocell coverage area or have no access permission to femtocell. In the core network, we use the proxy mobile IPv6 protocol (PMIPv6) [7] to enable this relay procedure. Furthermore, in order to encourage the femtocell owner to provide relay service, we consider a simple reward mechanism based on the data amount relayed by the femtocell. Similar to the one in multihop cellular network [8], this reward can be provided by the mobile service provider.

The rest of this paper is organized as follows. Section II defines the system model and discusses interference control to enable femtocell relay. Section III introduces related work. The proposed femtocell relay method is discussed in Section IV. Section V presents the simulation results and Section VI gives conclusions.

II. System Model

A. Network architecture

Fig. 1 presents the network architecture for this study, in which base stations (BS) and femtocell access points (FAP) are maintained under different mobile access gateway (MAG).

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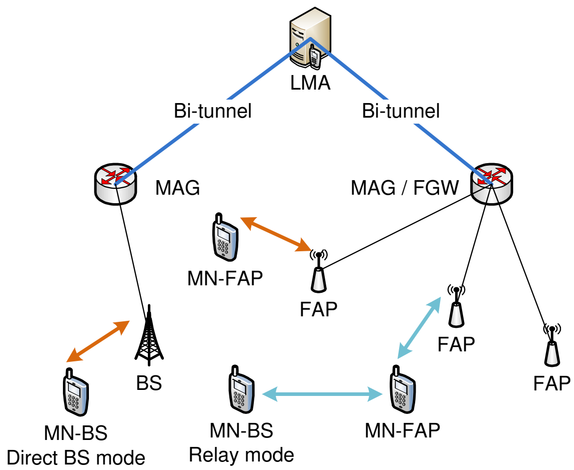

Fig. 1. Network architecture with femtocells and macrocells.

MAG is a network entity defined in PMIPv6 and is an access router that manages the mobility signalling for users attached to its access link [7]. Both MAGs in Fig. 1 are connected to a local mobile anchor (LMA) via bi-tunnel. LMA is another key network entity in PMIPv6, which is the home agent for mobile user in a proxy mobile IPv6 domain. It is also the topological anchor point for the user's home network prefix(es) and is the entity that manages the user's binding state [7]. A user connected to a BS and an FAP is referred to as *MN-BS* and *MN-FAP*, respectively. When an MN-BS connects to a BS or an MN-FAP connects to an FAP, MAG or femtocell gateway (FGW) will send a proxy binding update (PBU) message to register mobility information in LMA. LMA then creates a proxy binding cache entry (PBCE) for each MN-BS or MN-FAP. LMA sends all data destined to MN-BS or MN-FAP to a corresponding MAG based on this PBCE.

B. Interference control

As FAP works in the same spectrum range as macrocell BS, the transmit power of FAP need to be restricted in order to prevent interference with non-femtocell users. Given the network architecture in Fig. 1, the interference consists of that 1) between the macrocell BS and femtocell APs; 2) between femtocell APs; and 3) among multiple femtocell relay users (i.e., MN-BS nodes using relay service). Because of the small transmit power and penetration loss, it is reasonable to neglect the interference among different femtocells. Also, interference between the BS and FAPs has been extensively addressed in the literature. Therefore, in this paper, we focus on the interference among femtocell relay users.

To enable an effective femtocell relay method, we consider the channel allocation methods proposed in [9] and [10]. Firstly, femtocells reuse part of the channels allocated to the overlaying macrocell [9]. Secondly, in the relay mode, in order to control the interference among MN-BS nodes using the relay service, the femtocell AP can allocate one sub-channel to each pair of MN-FAP and MN-BS nodes during the relay establishment phase [10]. The MN-FAP and MN-BS can use this sub-channel to exchange signalling for establishment of a relay service connection. After that, the MN-FAP and MN-BS nodes can migrate back to the MN-BS node's original channel for data transmission between them. The details of channel allocation are given in Section IV.

III. Related Work

In the literature, there has been some research to exploit femtocells for data transmission. A new protocol is studied in [1] for femtocells to transfer data for a macrocell in order to decrease the traffic load in macrocell backhaul. All data sent to a user within a macrocell, referred to as *MN-BS*, are first sent to a femtocell AP (FAP) via the IP backbone network. The FAP then transfers the data packets to a user within its coverage area, referred to as *MN-FAP*. The femtocell node MN-FAP then transfers the data to the macrocell BS. At last, the macrocell BS sends the data to the final destination. Although the traffic load over the backhaul is decreased, this method increases the traffic load over the wireless link. Another approach to decreasing the traffic load with the macrocell BS is having a larger femtocell coverage area so that more users are connected to an FAP. However, this method can cause additional interference between macrocells and femtocells.

Multihop cellular networks (MCN) is another popular research topic related to this work. In MCN, cellular users (MN-BS) can explore multihop relay to connect to the BS. Obviously, this multihop relay scenario is very similar to that in Fig. 1. However, we cannot directly apply the existing protocols of multihop cellular networks for routing and channel assignment in in our scenario. In a MCN, all users are controlled by a central control node, i.e., the BS. Nonetheless, in a femtocell-enabled cellular network, users are separately managed by the FAP and the BS. Hence, certain cooperation with respect to channel allocation and mobility management is required between these two control nodes to establish relay service for MN-FAP and MN-BS users.

IV. Femtocell Relay Method for Load Sharing

As observed, a simple increase of femtocell coverage cannot provide effective load sharing due to additional interference to macrocells. In practice, femtocells are usually deployed in an indoor environment to limit the signal strength and minimize potential interference [11]. Based on this consideration, we introduce a femtocell relay method by exploiting indoor wired backhaul connections to share the traffic load for macrocells.

A. Femtocell relay service notification

As shown in Fig. 2, whenever an MN-FAP node would provide relay service, it first sends a relay request message to the associated FAP. Then the FAP allocates a channel, which is a sub-channel of the connection between MN-FAP and FAP, to the MN-FAP node. MN-FAP use this sub-channel to exchange control signalling with the MN-BS nodes who want to use the relay service. This multi-channel method can avoid the co-channel interference among different MN-BS and MN-FAP relay connections. After the exchange of relay request and channel allocation messages, the FAP broadcasts a

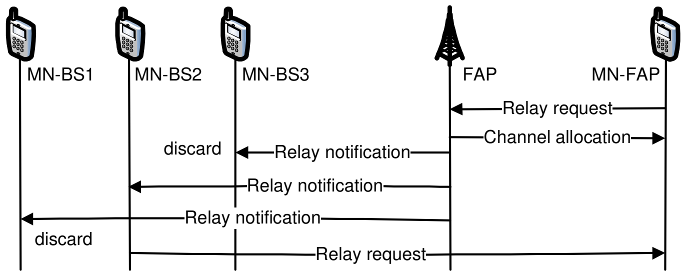

Fig. 2. Femtocell relay service notification.

relay notification message over the broadcast channel (BCH). The relay notification message should contain the address of the MN-FAP and the sub-channel information. In order to guarantee that MN-BS nodes outside the femtocell coverage area can hear this message, the transmit power to delivery this notification message should be several times larger than normal transmit power within the FAP. Meanwhile, this transmit power level should not be too large to introduce intolerable interference for the macrocell.

On the other hand, due to the power consumption concern, we have the FAP to broadcast the relay notification rather than the MN-FAP node itself. It is also to save the limited transmit power of the MN-FAP node. In addition, we assume that all FAPs under the coverage area of one macrocell BS use the same broadcast channel as the BS. Femtocell AP can obtain the broadcast channel information during the start-up process. Thus, we can ensure that all MN-BS nodes attached to a macrocell BS but close to an MN-FAP node can receive the relay notification message and be aware of the relay access. The FAP always broadcasts the relay notification message periodically, such as 10 times per minute, until there is no MN-FAP node in its coverage area would provide the relay service. Once an MN-BS node hearing the notification message does not want to use the relay service, it simply ignores and discards this message. Otherwise, the MN-BS nodes responds a relay request to the MN-FAP via the assigned sub-channel.

B. *Femtocell relay service establishment*

The relay service establishment must be authorized by the network side. One reason for this procedure is that network entities need to update the mobility management information for the MN-BS node to use the relay service of the MN-FAP node. Another reason is that the network entities need to track and calculate the reward amount based on how much traffic the MN-FAP forwards for other users. Also, the network can deny a relay request because of the heavy traffic load in the femtocell gateway (FGW). Fig. 3 illustrates the procedure to finally establish relay service connection. The main network control entities, mobile access gateway (MAG) and local mobile anchor (LMA), are involved with two basic operations.

Firstly, LMA and MAG for the macrocell BS (referred to as *MAG-BS*) suspend but do not delete the MN-BS node's routing information during relay service period. Therefore, MN-BS can migrate back to the BS immediately without any additional PMIPv6 registration. Secondly, LMA and MAG-BS need to return the channel information for the MN-BS to MN-FAP nodes so that MN-BS can use the same channel to communicate with MN-FAP. The purpose of this channel allocation is to save the channel resources in the macrocell. Once MN-FAP receives a relay request message, which is activated at the end of the relay notification phase, it further forwards this message to FAP, which contains the addresses of both MN-BS and MN-FAP nodes. If the traffic load in the FAP does not exceed certain threshold, the FAP sends the relay request message towards the femtocell gateway in the core network. Otherwise, it responds a relay acknowledgement with a denial indication. Then MAG-BS needs to send a proxy binding update (PBU) relay message to LMA. The relay PBU message contains the addresses of both MN-FAP and MN-BS nodes. Following that, LMA sets the routing information for MN-BS to a suspension state and updates the bi-tunnel end point to FGW. Consequently, LMA redirects data destined to MN-BS to FGW instead of MAG-BS. In the meantime, LMA sends a proxy binding acknowledgement (PBA) suspension message to MAG-BS. MAG-BS then suspends the routing information for MN-BS. MAG-BS gets channel information of MN-BS from the associated BS and sends it back to LMA through the PBU suspension message. LMA then responds to FGW with a PBA relay message containing the channel information of MN-BS. If MAG and MAG-BS are located in one entity, MAG can reply relay ack message directly to FAP.

Finally, the MN-BS and MN-FAP nodes can start to communicate through the original channel assigned by the macrocell than the initial sub-channel for both data traffic and relay control signalling. BS can reallocate the original MN-BS channel, which is released now, to other users. Apparently, this relay method does not waste any channel resource since the channel allocated to MN-BS within the macrocell BS is reused in the relay mode.

C. *Femtocell relay service termination*

To terminate the femtocell relay service, we can follow a reverse procedure as to the establishment signalling shown in Fig. 3. It recovers the routing information in LMA and MAG-BS to the original states. The signalling messages for relay termination should be similar except that a relay termination message can be used instead of a relay request message. The trigger for femtocell relay termination can be either a relay termination message sent by MN-BS or MN-FAP, or a link-layer attachment message sent from BS. The second case implies that the MN-BS or MN-FAP is moving out of the transmission range of each other. It is reasonable to assume that MN-FAP is responsible to send a relay termination message to the femtocell AP and MN-BS before stopping the relay service initiated by MN-FAP. When the MN-BS node moves out of the transmission range with MN-FAP, MN-BS can migrate back to its original BS and directly send data with the initial channel. Once MAG-BS detects packets from MN-BS or a link layer attachment message from BS for MN-BS, MAG-BS sends a PBU relay termination message to LMA so as to recover the routing information of MN-BS.

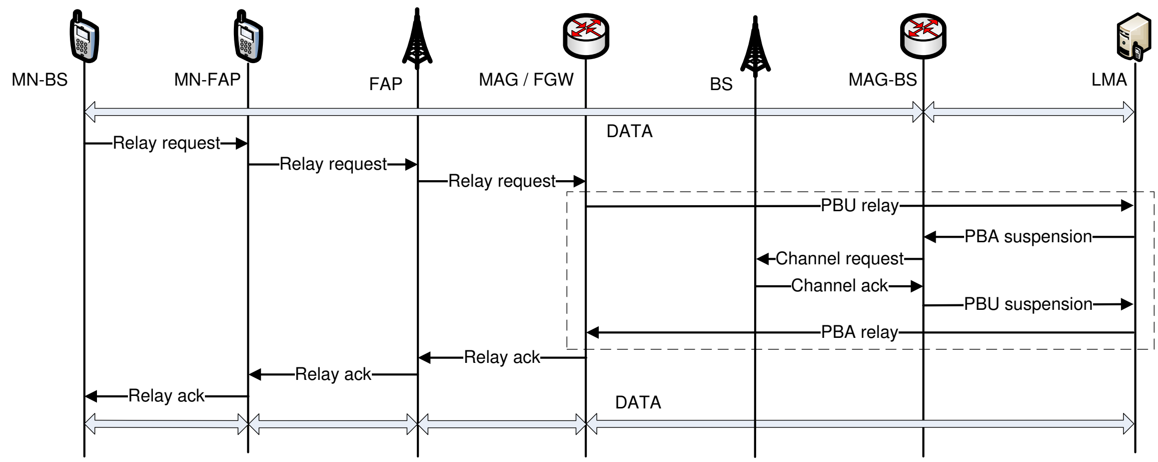

Fig. 3. Femtocell relay service establishment.

D. Implementation consideration

Our implementation strategy for the femtocell relay service is to reuse the existing signaling of PMIPv6 as much as possible. In PMIPv6, MAG periodically multicasts Router Advertisements (RA) to announce its multicast interface address, so that MNs listen to RA to discover the addresses of neighboring MAGs. Once an MN detects a link set-up with MAG, it sends Router Solicitation (RS) to MAG to request immediate RA rather than wait for the next periodic RA. In femtocell relay service, we can reuse the RA and RS messages and add new options. Specifically, we can include a relay request option within RS for MN-FAP to use this RS message as relay request in relay service notification. The same strategy can be adopted in other relay controlling messages.

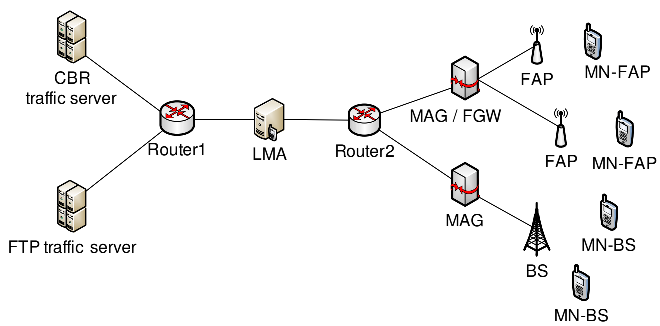

Fig. 4. Network architecture for simulations.

V. Simulation Results and Discussion

A. Simulation scenario

To evaluate the performance of the proposed scheme, we have implemented the relay method with NS2 simulator. Fig. 4 shows the simulation scenario for the following experiments. As seen, there is one base station connected to a mobile access gateway (MAG). Further, multiple femtocell access points (FAP) are deployed within the coverage of a macrocell BS. All of these FAPs are managed with on femtocell gateway (FGW). Also, a local mobile anchor (LMA) entity maintains the mobility information for all users in the wireless network.

TABLE I

Network parameters for simulation study.

Simulation parameter	Sample value
Number of users	200
Number of femtocells	$0 \sim 50$
Radius of base station	500m
Radius of femtocell	20m
Relay service range	100m
Femtocell backhaul bandwidth	8 Mbit/s
Base station backhaul bandwidth	50 Mbit/s
UDP traffic rate	10 kbit/s
UDP packet size	8000 bits
TCP window size	20 kbits

In our simulations, we consider totally 200 nodes, including both MN-BS and MN-FAP. Within each FAP, assume only one MN-FAP node would provide relay service. The deployment of MN-BS nodes and femtocells follows a uniform distribution in the macrocell BS coverage, which is assumed to be a circle of radius 500 m. The BS manages channel allocation to MN-BS and a different channel is assigned to each MN-BS node. The femtocells reuse part of channels available to BS, while each FAP is assigned a different channel. For simplicity, we assume that all FAP nodes broadcast relay notification simultaneously. With respect to traffic load, we simulate both constant bit rate (CBR) traffic based on user datagram protocol (UDP) and variable bit rate (VBR) traffic for file transfer protocol (FTP), which is running over transport control protocol (TCP). The detailed simulation parameters are given in Table I, which are selected by referring to related work in [1,12].

B. Simulation results

To examine the effectiveness of the femtocell relay method, we first investigate the traffic over BS when increasing the number of femtocells contributing to relay service. As seen in Fig. 5, the traffic load directly delivered over the BS wireless links is greatly reduced when a larger number of femtocells are

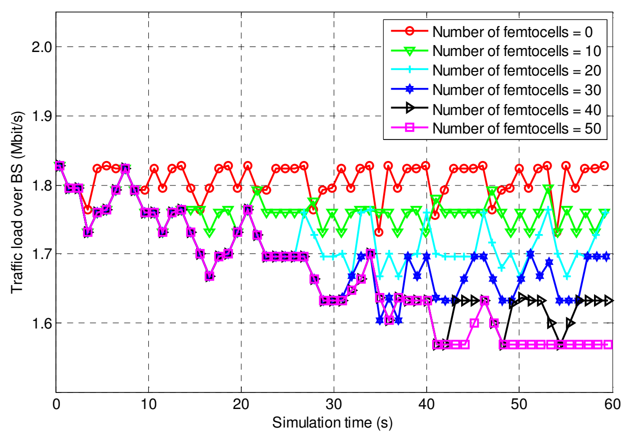

Fig. 5. Traffic load over BS with a different number of femtocells.

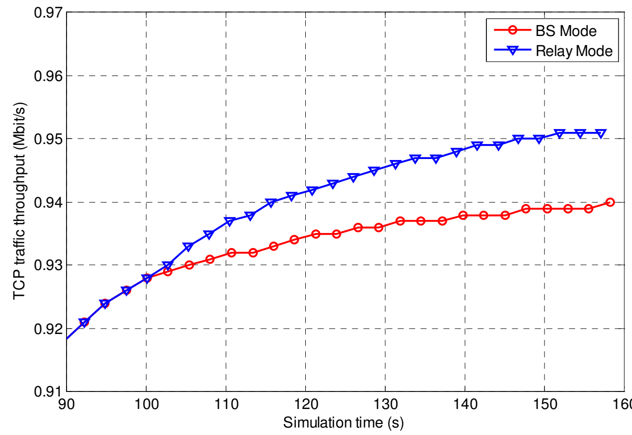

Fig. 7. TCP traffic throughput in relay mode and direct BS mode.

involved with the relay service. This is exactly what we expect for femtocell nodes to share the traffic load for BS and relieve congestion with wireless links. When a larger number of femtocells participate in relay service, more traffic is redirected from BS towards the wired network behind femtocells.

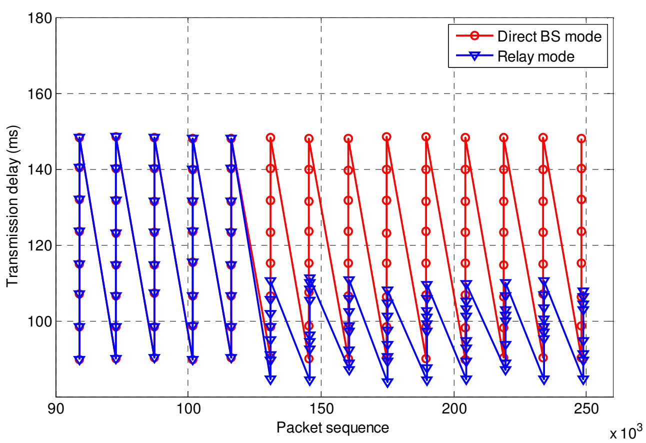

Fig. 6. Transmission delay of UDP traffic in relay mode and direct BS mode.

Moreover, we have compared the performance of UDP and TCP traffic when a relay mode is activated or not. As seen in Fig. 6, when the relay service is activated, the transmission delay of UDP packets for MN-BS greatly decreases from 120 ms to 100 ms on average. Furthermore, the delay jitter is also significantly reduced from 50 ms to 15 ms. On the other hand, Fig. 7 shows the TCP traffic throughput is increased when the relay service is used. Although the total bandwidth of BS backhaul is much higher than that of FAP backhaul, the channel bandwidth assigned to each MN-BS is much smaller than that of MN-FAP. A great number of MN-BS users need to be accommodated by the BS within a large coverage area. Also, we can see from Fig. 7 that no service interruption is observed during the relay service period. This is because we enable *make-before-break* handover, i.e., soft handover by exploiting femtocells at the same operating spectrum. In other words, the network entities can establish a new relay connection before handover so that MN-BS can transfer data to MN-FAP without any interruption.

VI. Conclusion

In this paper, we have studied a new femtocell relay method for load sharing to macrocells. In the proposed method, a femtocell AP (FAP) first broadcasts relay service notification on behalf of femtocell nodes (MN-FAP). Once hearing the relay service notification, a macrocell user (MN-BS) within the vicinity of the femtocell node can acknowledge to initiate a relay connection. Considering the proxy mobile IP v6 protocol (PMIPv6) framework, we have presented detailed procedures for relay establishment and relay termination. Our simulation results have shown the relay method can effectively balance the traffic load for macrocell base stations and improve the delay and throughput performance of macrocell users.

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