Efficient Routing of Data for Femtocells

Pavel Mach and Zdenek Becvar
Department of Telecommunications Engineering, Faculty of Electrical Engineering
Czech Technical University in Prague
Technicka 2, 166 27 Prague, Czech Republic
machp2@fel.cvut.cz, zdenek.becvar@fel.cvut.cz

Abstract— **The paper proposes novel routing method for two users connected to the same femtocell communicating with each other. In conventional case, data are sent in two sequential steps. In the first step, data are transmitted from the user to the femtocell. In the second step, data have to be retransmitted to other user. We suggest transmitting user's data directly instead of two hop communications if both users are sufficiently close to each other. In addition, we propose exchange of management messages in order to implement our routing scheme in LTE-A standard. The simulation results indicate that the throughput offered by femtocells can be significantly increased.**

Keywords- femtocells; routing; control procedure; LTE-A

I. Introduction

The Femto Access Points (FAPs) are small and low cost base stations located typically within buildings with the purpose to improve Quality of Service (QoS) for indoor users [1]. The FAP is connected to the operator network via wired link exploiting xDSL, cable, or optic fiber connection. Thus, the problem of femtocells may consist in insufficient backbone capacity acting as a bottleneck at the side of the FAP. Further, as the data are sent to the operator via all IP network, the FAP's users can suffer from decreased QoS.

There are already several studies which objective is to avoid data transmission over the Internet if possible (i.e., when source and destination stations are located within the same company, campus, or building). In [2], the authors propose Femto Private Branch Exchange (FPBX) to concentrate traffic of several FAPs in specific areas such as an enterprise or a campus. The advantage of FPBX is that the calls within the enterprise are routed in similar way as in case of conventional PBX. Thus, the cost of the call is reduced. The route optimization for data in femtocell networks is proposed in [3]. The authors suggest to route data directly between two FAPs that are in close vicinity of each other. This approach offloads FAP's backbone.

This paper proposes novel routing scheme in order to make data transmission in networks with FAPs more efficient. We propose to route data transmission directly between User Equipments (UEs) on the condition that the UEs are within communication distance. This can be applied if two UEs attached to the same FAP are communicating between themselves. The UEs are transmitting data in similar way as in ad hoc network but the FAP coordinates all the communication and data transmission. This way, the data are sent via only one hop instead of two hops path and FAP's radio resources are utilized more efficiently.

The principle is described on the assumption that the femtocells utilize LTE-A technology with TDD duplex [4]. Nonetheless, the general principle can be applied for other technologies such as LTE or WiMAX utilizing TDD or FDD.

II. Proposed Routing Scheme

In conventional way (e.g., according to [2][3]), data have to be transmitted two times if UEs currently attached to the same FAP communicate between themselves (see Fig. 1). Firstly, the data are sent from the UE1 to the FAP. Secondly, the FAP relays data to the UE2. As this approach waste radio resources, we propose to route data directly whenever feasible. In other words, when the UE1 and UE2 are not within communication distance, data are sent similarly as in the conventional approach. However, if the channel quality between UE1 and UE2 becomes sufficient enough (e.g., due to UE's movement), the former routing path is changed to direct one as suggests Fig. 1. Note that this condition is satisfied in most of the cases as UEs are located in close vicinity.

The proposed control procedure is shown in Fig. 2. The suggested enhancements are highlighted by red color. If UE1 has data for the UE2, it sends scheduling request to the FAP in order to get allocation of radio resources in uplink (UL) direction. The request is conveyed via Physical Uplink Control Channel (PUCCH). If UE has not enough of radio resources, it has to perform random access procedure via Physical Random Access Channel (PRACH). As a response, the FAP either grants required amount of radio resources through Physical Downlink Control Channel (PDCCH) or not. In the former case, the UE1 starts transmit its data to the FAP at scheduled intervals. At the same time as the grant is sent to UE1, the FAP orders the UE2 to measure the signal quality received from the UE1, i.e., the UE2 has to estimate the quality of channel between the UE2 and currently transmitting UE1. The FAP's request is sent through PDCCH channel. To accomplish the measurement, the UE2 must know the exact time and frequency allocation of UE1's transmission and position of its RSs. Consequently, the FAP also specifies a time interval during which the UE1 is transmitting (defined in PUCCH message as well). The channel quality between UEs needs to be measured to allow the FAP to select appropriate path for data routing. Note that user's data from UE1 to UE2 are still transmitted via FAP during measurement.

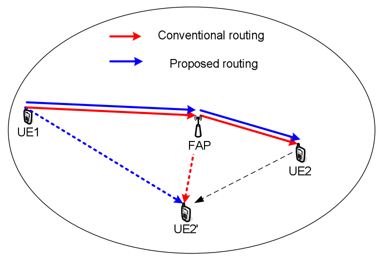

Figure 1. Data routing between two UEs connected to the same FAP

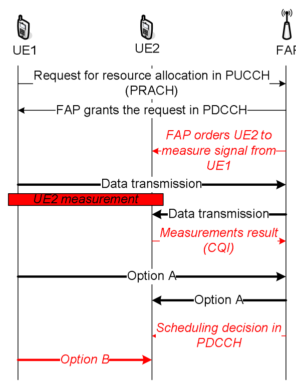

Figure 2. Control procedure for proposed data routing

After the UE2 performs the measurements, the results are conveyed to the FAP via CQI sent in PUCCH. At this stage, the FAP has to estimate whether the direct transmission or transmission through the FAP is more appropriate. To select best routing path, the FAP takes quality of all involved routes into account. Besides the channel quality between UEs, the state of other two channels (from the UE1 to the FAP and from the FAP to the UE2) must be obtained at the side of the FAP. The channel quality between the UE1 and the FAP is known since the FAP receives data from the UE1 in the meantime. Similarly, the channel quality between the FAP and the UE2 is known since the UE2 reports channel quality periodically to the FAP to select suitable Modulation and Coding Scheme (MCS) in downlink (DL) direction.

Based on measurement, the FAP is able to calculate the optimal path between the UE1 and UE2. The calculation of proper route can be done according to several metrics. For this purpose we use so called Radio Resource Cost (RRC) metric [5]. This metric estimates the amount of radio resources that have to be assigned for transmission of certain amount of data via all possible routes. The RRC between station x and station y can be expressed as:

$$RRC_{x-y} = \frac{D}{\Gamma_{x-y}(MCS)}. \tag{1}$$

where D corresponds to the amount of data transmitted from the UE1 to the UE2 and Γ represents the transmission efficiency determined according to MCS reported by means of CQI. The FAP selects the path in accordance to the following formula:

$$\begin{aligned} &path = i \mid P_i = \min\{P_1, P_2\}; \\ &P_1 = RRC_{UE1-FAP} + RRC_{FAP-UE2}; P_2 = RRC_{UE1-UE2} \end{aligned} \tag{2}$$

Immediately as the proper path is selected, the FAP either continue to retransmits UE1's data to the UE2 (in Fig. 2 labeled as "option A") or send new decision in PDCCH to synchronize UE2's receiving intervals with UE1's transmission intervals (in Fig. 2 labeled as "option B"). As long as the UE1 transmits data to UE2, the FAP has to be continuously aware of the quality of individual involved paths in order to adaptively select the appropriate routing path. Note that the path may change during the UE1's transmission, if necessary, from one hop to two hops and vice versa.

The signaling overhead introduced by the proposed routing contains three components: i) the FAP sends order measuring signal quality between the UEs, ii) the UEs report their measurement results by means of CQI, and iii) the FAP transmits new scheduling decisions when routing path is changed. The overhead generated by the first component is negligible since the command is sent only once at the beginning of UE's transmission. Similarly, the third component does not increase overhead as the new scheduling of data allocation has to be transmitted only if the path is changed. Thus, the only notable additional overhead introduced by the proposed procedure is due to second component. This part of overhead depends on the number of users attached to the FAP, number of antenna of UEs, the amount of bits necessary to report CQI, and the duration of reporting interval. Still, the overhead generated by the reporting is not significant for femtocells. First, the number of users attached to the one FAP is very limited. Second, the size of CQI report is in order of bits at most [6]. Third, the reporting period is proportional to the speed of users and frequency of channel conditions changes. The users located within building could be assumed to move very slowly or to be fixed. Thus, the reporting could be done relatively infrequently and set to higher values such as 80 or 160 ms [6]. In the worst case scenario, the overhead is up to 0.15% (see Fig. 3).

III. EVALUATION OF THE PROPOSAL

In order to evaluate proposed routing scheme, simulations in MATLAB environment are performed with parameters' setting indicated in Table 1. The system model contains one hundred terraced houses with structure according to [7]. The disposition of the houses is depicted in Fig. 4. The FAPs are deployed uniformly in half of the houses. The outdoor users are moving only within sidewalk's boundaries from the south to the north with speed of m/s along straight trajectories.

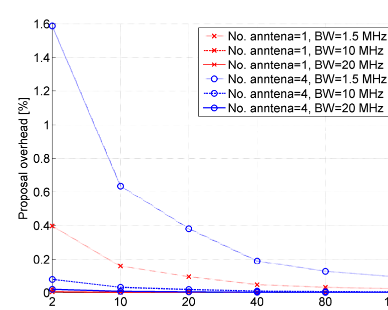

Figure 3. Reporting overhead due to proposed routing procedure

TABLE I. SYSTEM SETTINGS

Parameter	Value
Carrier frequency [GHz]	2.0
MBS/FAP channel bandwidth [MHz]	10
Frame duration [ms]	10
Number of OFDM symbols per slot [-]	7
MBS transmit power [dBm]	43
Max. FAP transmit power [dBm]	21
Outdoor UE transmitting power [dBm]	15
No. of FAPs	50
Loss of int. wall/ext. wall/window [dB]	5 / 10 / 3
Outdoor path loss model	ITU-RP.1238 model
Indoor path loss mode	COST 231 model
Noise [dBm]	BW·4·pW/GHz
Physical layer overhead [%]	25
Real-time duration of simulation [s]	5 000

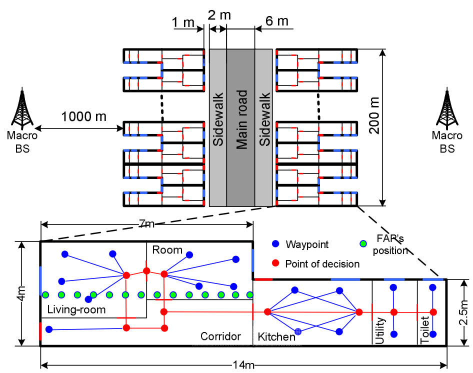

Figure 4. Simulation scenario

Their distance from the house is selected randomly with equal distribution in range varying between 1 m to 3 m from the house. The intensity of UEs arrival to the system follows Poisson distribution and it corresponds to approximately 70 passing users per one hour. The only purpose of outdoor users is to emulate interference in UL for the FAP's UEs.

Each house equipped with FAP contains four UEs whose movement within the house is based on [7] as illustrated in Fig. 4. The UEs are moving along predefined trajectories between waypoints and points of decision. Since the performance of both investigated routing schemes is influenced also by the FAP's location in the house, several positions are selected as shown in Fig. 4. The simulation is run for all FAPs' position and after that the results are averaged out.

A. Results

The simulations evaluate the performance of conventional and proposal schemes for VoIP and FTP traffic models. In this scenario we estimate achieved bit rates when transmitting FTP files between two UEs attached to the same FAP. The model itself generates data files of sizes up to 12.5 Mbytes according to lognormal distribution. The time between two files is on the average 1.7 s, which is given by exponential distribution. To emulate background traffic, that is, data that are not sent between two UEs of the same FAP, a combination of VoIP and FTP models is used. The amount of traffic generated by FTP alone is on the average 4.4 Mbit/s.

Fig 5 shows a distribution of bit rates over whole simulation time and over all FAP's position. In case of the

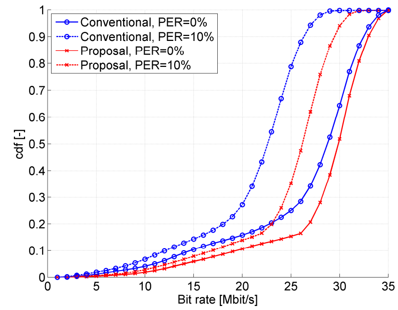

Figure 5. Bit rates of transmitted FTP files

conventional routing scheme, 75% of files are sent with transmission speed higher than 25 Mbit/s if packet error rate (PER) is non existent. In case of our proposal, approximately 85% is sent with bitrates higher than 25 Mbit/s. In the case of PER=10%, the performance of conventional scheme is especially negatively influenced as 80% of files are delivered with lower bitrates than 25 Mbit/s. On the contrary, proposal performance is not that much degraded since only 35% of generated files are sent with bitrates lower than 25 Mbit/s.

IV. CONCLUSIONS

The paper proposes novel routing scheme of data transmission for UEs attached to the same FAP. The results demonstrate that the proposal enhances FAP's performance in terms of system throughput. Consequently, the QoS for indoor users can be notably improved.

ACKNOWLEDGMENT

This work has been performed in the framework of the FP7 project FREEDOM IST-248891 STP funded by the European Community. The Authors would like to acknowledge the contributions of their colleagues from FREEDOM Consortium.

REFERENCES

[1] Z. Bharucha, H. Hass, I. Cosovic, and G. Auer, "Throughput Enhancement Through Femto-Cell Deployment," *Lecture Notes in Electrical Engineering*, vol. 41, pp. 311-319, 2009.

[2] Y.-B. Ling, Ch.-H. Gan, and Ch.-F. Liang, "Reducing Call Rouitng Cost for Femtocells", *IEEE Transaction on Wireless Communications*, vol. 9, pp. 2302-2309, 2010.

[3] T. China, and H. Yokota, "Efficient Route Optimization Method for Femtocell-based All IP Networks", IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, pp. 221-226, 2009.

[4] 3rd Generation Partnership Project, 3GPP TS 36.300 v 10.0.0, "Technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); physical channels and modulation," Release 10, June 2010.

[5] Z. Becvar, P. Mach, and R. Bestak, "Initialization of Handover Procedure in WiMAX Networks", ICT-Mobile Summit, p. 110-119, 2009.

[6] S. Sesia, I. Toufik, and M. Baker, "LTE – The UMTS Long Term Evolution – From Theory to Practice", ISBN 9780470697160, 2009.

[7] H. Claussen, S. Pivit, and L.T.W. Ho, "Self-Optimization of Femtocell Coverage to Minimize the Increase in Core Network Mobility Signalling," *Bell Labs Technical Journal*, vol. 14, no. 2, pp. 155-183, Aug. 2009.