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Site-specific study of in-building wireless solutions with Poisson traffic

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Abstract—**Due to the poor outdoor-to-indoor propagation into buildings, dedicated wireless systems installed inside the buildings are often preferred for providing indoor users with high-data-rate services. We study the typical in-building wireless solutions - distributed antenna system and small cell Femto system - together with another multi-cell system using our proposed centralized scheduling scheme. In our previous work, their performance is evaluated and compared in the LTE downlink context with full buffer traffic. Compared to real mobile networks, the full buffer traffic model is usually a worst-case estimation of traffic load which causes severe interference conditions. Especially for Femto cells with universal frequency reuse it degrades system performance and may lead to biased conclusions on the relative performance of the different in-building solutions. In this study, we use a more realistic traffic model with fixed buffer size and Poisson arrival. Our new results show better performance for Femto cells with frequency reuse 1 at light to medium load, although the intelligent distributed system still obtains considerable better cell edge user throughput for the same number of access points.**

I. Introduction

Along with the popularity of multi-media services over wireless communication systems, the data rate demand from end-users also increases rapidly. The traditional macro-cell deployment has become inadequate to offer sufficient data rate to the users for these services [1]. The situation is even more severe in the in-building systems, where the macro-cell signal is significantly reduced due to the penetration loss of the building. Therefore, it is desirable to deploy dedicated in-building wireless systems to fill coverage holes and provide additional capacity [1][2].

Several solutions have been previously developed, including the Distributed Antenna System (DAS) [2][3] and a system of small independently operating Femto base stations [4]. These systems can use the same carrier frequency as the outdoor macro-cell, i.e., the co-channel mode, or occupy a different (usually higher) frequency band [5].

In this paper, the deployment solutions of DAS, Femto systems and the proposed intelligent distributed system (I-DS) with joint centralized scheduling will be analyzed in the LTE downlink context using co-channel deployment with the macro-cell. I-DS was developed in our previous work [9], and will be further discussed in the following sections. The analysis in [9] was based on a simple full buffer traffic model. By using a full buffer traffic model, we assume all distributed network elements are actively transmitting continuously in their entire allocated frequency band, which leads to maximum interference towards all users. This phenomenon is expected to harm especially the multi-cell Femto system, because strong neighbor cell interference is unavoidable. However, with a finite buffer model, users arrive and depart the system according to certain arrival rate and buffer size, respectively, making the load in the network more dynamic. As a consequence, this frees some of the users from neighbor cell interference.

In our previous study [9] we conclude that for a single input single output (SISO) system, Femto cells with frequency reuse 2 outperform Femto cells with reuse 1, however with the recommendation that careful planning is used for the deployment of the Femto cells under reuse 2. Similar conclusions are found in other works with residential Femto deployments [6][7]. Both Femto cells with reuse 2 and I-DS use a strategy whereby spectrum resources are sacrificed for better SINR conditions. This paper extends our previous work; tries to clarify how the more dynamic interference condition brought about by the finite buffer traffic model will impact this tradeoff, hence change the performance balance between reuse 1, reuse 2 and between I-DS and the Femto system.

The rest of the paper is organized as follows: Section II introduces the different in-building deployment solutions that are considered in this paper; Section III describes the simulation methodology and assumptions; In Section IV, the performance for the investigated solutions is evaluated and compared against each other. Finally, Section V concludes the paper.

II. In-building Wireless Solutions

In this section we will shortly introduce the wireless deployment solutions for the in-building wireless system.

A. Distributed Antenna System (DAS)

DAS is a single-cell system with multiple remote antenna-elements. These antenna-elements are connected to the base station and broadcast the same radio signal of one cell/sector in the downlink. Similarly, in the uplink direction, the received signals at the different antenna-elements will be combined at the base station. Each of the antenna-elements can be considered as a low power Access Point (AP). The spatially distributed APs shorten the distance to user equipments (UE), thus help in extending the coverage area. However, because of the broadcast operation the frequency resources are not reused within the system, hence, when the

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number of APs becomes sufficiently large for good coverage, the system capacity will saturate, and there will be no extra gain from deploying more APs. Potentially, it is possible to deploy multiple DAS to distribute radio from multiple sectors in one building, but in a small-to-medium sized building, as studied in this paper, a single-cell DAS is commonly adopted. We use the term single-cell DAS (SC-DAS) to make clear our chosen DAS system is a DAS that distributes radio from a single cell/sector.

B. Femto system

Femto system is a multi-cell system with independently operating APs. There is little or no information exchange between the APs, and hence they most likely commit uncoordinated packet scheduling. In this study, we assume there is no information exchange on transmission coordination and packet scheduling is uncoordinated. The placement of APs will be introduced in section III. The total system bandwidth with Femto deployment increases proportionally with the number of APs. However, having more APs also increases the inter-Femto interference which in turn brings down the achievable spectrum efficiency per user. For the Femto cell solution, it has been found in [9] that the placement of the Femto APs has a significant impact on the system performance. We have chosen here the aligned placement suggested in [11] in the simulation setup and used an offset placement to verify the performance of Femto cells with non-optimal placement.

Femto performance can be optimized by radio planning with frequency reuse. For example, improving the signal quality with frequency reuse 2 can be beneficial, despite the cost of halving the available bandwidth for each Femto-cell. The selection of proper reuse-factor depends on the cell load as well as the number of APs, as will be analyzed later.

C. Intelligent Distributed System (I-DS)

The idea of I-DS is proposed in [9] and its architecture is similar to a distributed base-station system or base-station hotel, where a set of base-stations are co-located and radio signals are distributed by remote antenna units. In contrary to an ordinary DAS system, the signal distribution of I-DS is based on a one-AP-per-cell basis, i.e. the air-interface of one cell/sector is composed of only one remote AP. Similar as the Femto, it is also a multi-cell system with inter-AP interference. However, the co-located feature of I-DS base-stations makes it possible to build a local central controller and conduct centralized coordination among all involved cells. Unlike Femto system with interference coming from all surrounding APs, I-DS is able to block some APs from transmitting on certain time/frequency resources. The blocking of APs is based on the user path loss measurement. I.e., if a user is scheduled on one AP (with the smallest path loss among all APs), all the other APs that have a path loss value within a certain blocking threshold (see Table I) of the serving AP will be blocked, since they will generate high interference to this user. A centralized packet scheduler is needed for the transmission over multiple APs in the central controller.

In fact, I-DS offers the trade-off between bandwidth and signal quality, which is similar to the Femto cells with frequency reuse 2. The main advantages of I-DS are:

1. The signal quality – bandwidth trade-off is automatically performed by the blocking of APs, based on channel measurements. Therefore, it does not need the selection of frequency reuse factor or reuse planning.
2. The blocking can potentially operate on the smallest resource block for scheduling (per PRB, introduced in section III) which has a much finer resolution than the allocation based on which frequency reuse is done. Consequently, I-DS offers a higher degree of freedom compared to the Femto system.
3. I-DS adapts bandwidth allocation on each AP to the prevailing interference condition which leads to better utilization compared to the fixed frequency reuse in the . Femto system.

However, the cost of I-DS is the joint scheduling, which increases processing burden at the central controller.

III. SCENARIO DESCRIPTION AND SIMULATION ASSUMPTIONS

The site-specific building model and the model for the surrounding macro-cell interference is described in our previous work [9] and used again for the performance evaluation in this paper. The path loss model is empirically derived from measurements in the building shown in Figure 1 [8].

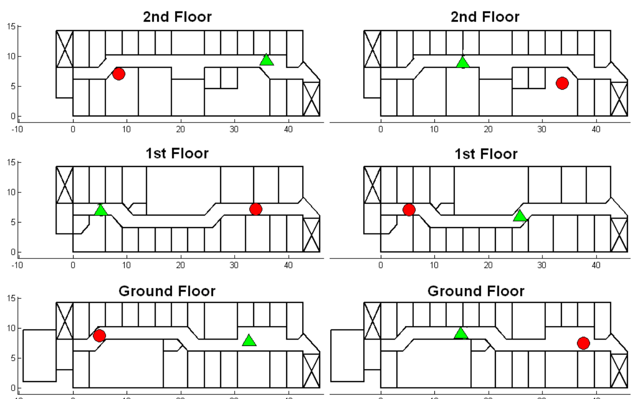

Figure 1 Site-specific building floor plan and two examples of 6-AP placement (left: optimal placement, right: non-optimal placement)

The building has three floors and the rooms in each floor are separated into two stripes by a corridor. In the figure, a case with 6 APs (2 on each floor) is shown, with different shaped markers representing distinct frequency channel, if frequency reuse 2 is applied. The figure on the left illustrates the case with APs deployed as to optimize the performance of the system. The figure on the right side illustrates the case when the APs are placed less fortunate and leads to worse signal conditions [11]. The simulation results of these two configurations will provide an insight into the impact of AP placement on system performance.

The performance of the different techniques is evaluated in a downlink system level simulator that follows the LTE specifications defined in [10], including Layer-2 packet scheduling, Hybrid Automatic Repeat Request (HARQ) and link adaptation functionalities. The resolution of scheduling on the time domain is per 1ms or so called one TTI and on the frequency domain is per 180 kHz, which form a physical resource block (PRB). One PRB is the smallest resource block that scheduling can operate on. The simulation process is conducted as a single simulation with long simulation time (up to 50 seconds), which can offer sufficient statistics when users are created and terminated dynamically during the simulation. We use fixed user buffer size of 2 Mbits and vary user arrival rate to examine the performance of each system under diverse offered load, where the offered load is calculated by multiplying the user arrival rate with the buffer size. The simulation parameters are summarized in Table I.

TABLE I
SYSTEM SIMULATION SETTINGS

Parameter	Setting / description
System bandwidth	5 MHz bandwidth with 25 PRBs
Modulation and coding schemes	QPSK (1/5 to 3/4) 16-QAM (2/5 to 5/6) 64-QAM (3/5 to 9/10)
HARQ modeling	Ideal chase combining with maximum 4 transmissions.
Feedback period and delay	Feedback every 5 ms, with 6 ms delay
Layer-2 packet scheduler	RR for SC-DAS and Femto; joint scheduling with equal-share for I-DS
1st transmission BLER target	10%
Traffic model	Finite buffer with Poisson arrival.
AP transmit power	20 dBm (100 mW)
I-DS blocking threshold	10dB
Mean signal strength from macro site (within indoor area)	-143dBm/Hz

IV. PERFORMANCE

In this section, the performance of different in-building wireless solutions is evaluated and compared. The following performance indicators will be applied:

- Average system throughput: the summed throughput over all cells in a certain system, averaged over time, in units of Megabit-per-second.
- Cell-edge user throughput: the 5%-tile worst user throughput from all simulated users.

A. *SINR distribution for different solutions*

We present the user SINR distribution of each system with full buffer traffic in Figure 2 to highlight the worst condition of inter-cell interference in each case. As can be seen from the figure, the highest downlink SINR is achieved with SC-DAS. This is expected because there is no inter-AP interference with SC-DAS, and the macro interference is relatively low after penetrating into the building. Femto system has the worst SINR distribution, because of full inter-Femto interference from all APs. I-DS has a SINR condition much improved over Femto system at the lower range due to the inter-AP interference avoidance by the blocking operation.

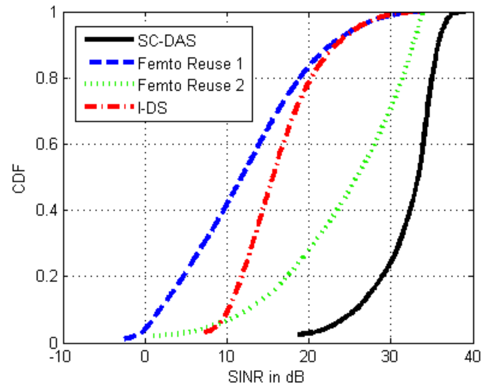

Figure 2. SINR distribution of different in-building wireless solutions with 6 APs and full load.

Although beneficial in terms of SINR, SC-DAS may not achieve as high performance as the other two solutions due to the low effective bandwidth per AP, which translates to low effective bandwidth per user. We first take a look at the cell-edge user throughput in the next section for the different solutions. The average system throughput will be presented later.

B. *Cell edge Performance*

The performance of cell-edge user throughput is a combined effect of both user SINR distribution and per user effective resource occupation, the former of which is subject to number of APs, placement of APs and cell structures. The performance of SC-DAS is summarized in Figure 3 with different arrival rates and different number of APs; and it decreases with the offered load. The decrease of cell edge performance is due to the fact that more and more users share the same amount of resources, as arrival rate increases. For very high arrival rate that the system cannot accommodate, the cell-edge user throughput will decrease to zero.

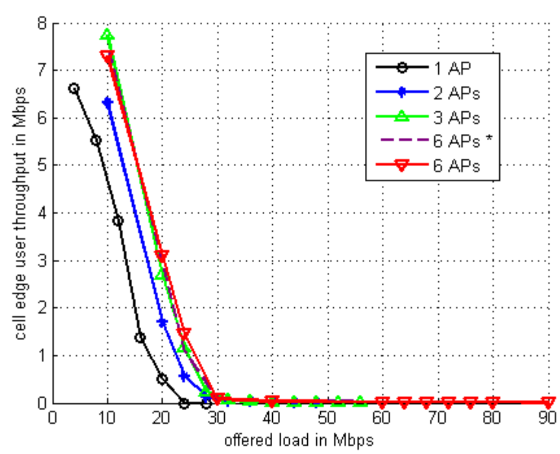

Figure 3. SC-DAS: cell-edge (5 percent) user throughput with different arrival rates and number of APs. (* non-optimal placement)

Looking at the performance with different number of APs, we notice that when user arrival rate is low, one AP is enough to achieve good performance. However, as the arrival rate increases, the gain of increased number of APs becomes clear. The performance saturates when number of APs is high enough to achieve very good SNR within coverage area in the building (in this case, 3 APs), beyond which the system cannot benefit by having more APs. The performance of SC-DAS with a non-optimal placement was also plotted in the figure (indicated by * in the legend). The results show that the non-optimal placement hardly has harmful impact on cell edge performance with high density deployment of remote APs. So the over-provisioning on AP density can help system overcome the defects of non-optimal AP placement.

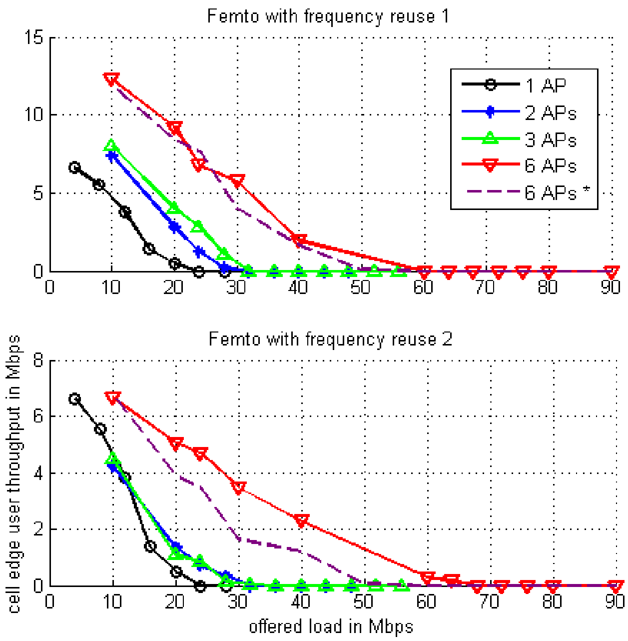

Figure 4. Femto cells: cell-edge user throughput with various arrival rates and number of APs. Different frequency reuse factors examined.

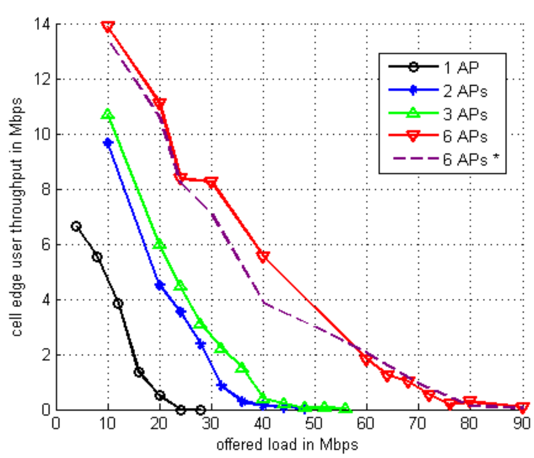

Figure 5. I-DS: cell-edge (5 percent) user throughput with various arrival rates and number of APs. (* non-optimal placement)

The performance of the Femto system is shown in Figure 4 for both frequency reuse 1 and reuse 2. Similar to SC-DAS, the performance decreases with the arrival rate. Between the two reuse factors, it is noticed that reuse 1 is beneficial when the system is lightly loaded (below 40Mbps), because in this case, only part of the Femto APs are serving users and the inter-Femto interference is low on average, Femto system with frequency reuse 1 benefits from more available spectrum resource per AP. At high load, all Femto-APs are actively transmitting and each cell generates interference to its neighbor cell in a frequency reuse 1 configuration. This is when reuse 2 system outperforms reuse 1. However, the gain provided by reuse 2 in high load is small compared with that of reuse 1 in light load: for example with traffic load up to 30 Mbps, reuse 1 achieves almost doubled cell edge capacity over reuse 2, however, the gain is less than 20% percent to the advantage of reuse 2 with load of 40Mbps. Also seen is that a non-optimal placement will deteriorate the performance for reuse 2 system, but not for reuse 1.

By increasing the number of Femto cells, unlike SC-DAS, the Femto system performance experiences a corresponding gain, and thus able to support much higher load.

For an I-DS system, the performance is shown in Figure 5. It has similar performance to Femto system, but does not need frequency planning and is less sensitive to AP placement. For I-DS it is also desirable to have a higher number of APs when offered load is high, while a few APs can provide good performance at low load.

C. Average System Throughput and Comparison between different solutions

For each of the considered solutions, their maximum system capacity is compared in this section. For the finite buffer model, the average system throughput is mainly determined by the offered load, and upper-bounded by the maximum system capacity. Their cell-edge performance is plotted again for comparison between the different solutions.

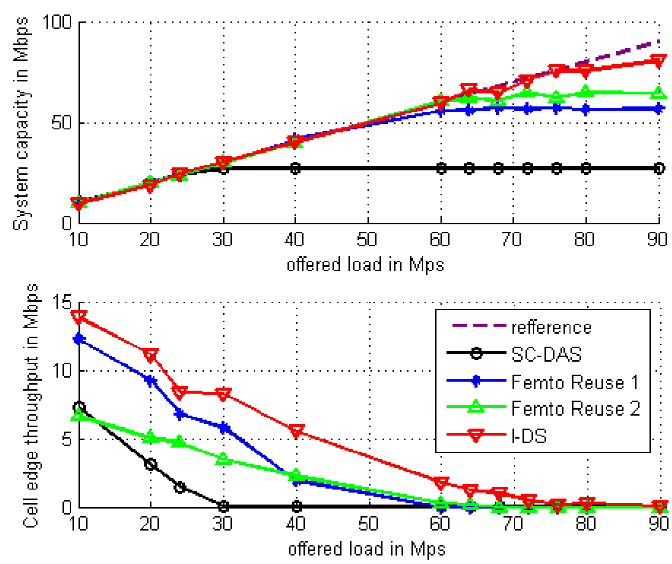

Figure 6. System capacity and cell-edge performance of various systems with 6 APs.

Figure 6 shows the comparison of systems with 6APs, including a reference line which draws when capacity meets the offered load. As can be seen from this figure, the average system throughput linearly increases with the arrival rate until the maximum system capacity has been reached. When the offered load further increases, the average system throughput remains at that level, but the cell edge user throughput quickly decreases to zero. In this case the users cannot be fully served by the system and will start to accumulate in the system. The advantage of I-DS can also be witnessed by the instantaneous number of users in the system during the simulation time. For example, the 6-APs I-DS system has an average of 3.3 users per TTI when the arriving rate is 20 users per second, equivalent to 40Mbit offered load per second, while there are on average 6.6 users per TTI in 6-AP Femto system. The user number of SC-DAS system keeps growing during the simulation time, because it is lack of capacity to serve the continuously arriving users and users become piled up in the system.

As seen from Figure 6, SC-DAS offers the lowest system capacity, and for the same arrival rate, it has the lowest cell-edge user throughput among the three solutions. The best performance is achieved by using I-DS, which is better than Femto cells with any frequency reuse configuration.

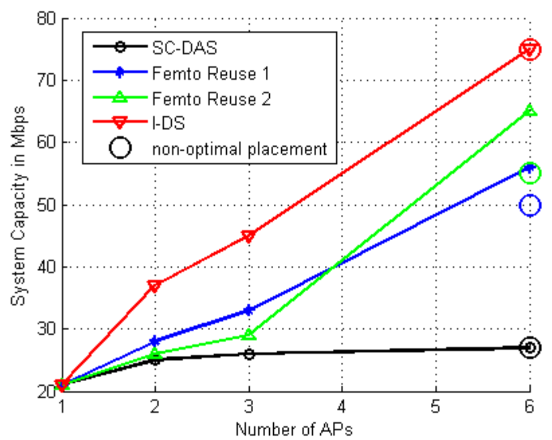

Figure 7. Maximum system capacity that can be supported by different systems with different numbers of APs.

We make a summary of maximum system capacity supported by each system with different numbers of APs in Figure 7. The advantage of the I-DS can be clearly seen from the figure; the SC-DAS system is limited by single cell peak data rate; and both systems is robust towards a non-optimal placement of APs. Femto system with a reuse 2 configuration can potentially outperforms reuse 1 system in maximum system capacity but the good performance is subject to a good placement of APs.

V. CONCLUSION

In this paper, the performance of different in-building wireless solutions is evaluated and compared in the LTE downlink context with co-channel deployed macro layer. This study is an extension of our previous work. The major enhancement made in this study is the use of a finite buffer traffic model with Poisson arrival. We observe that with a light-to-medium traffic load, multi-Femto system with frequency reuse 1 achieves on average a better performance than reuse 2 system, which alters our previous conclusion based on the full buffer traffic model. This is because with dynamic traffic load, chances are that only parts of the Femto APs are active at the same time. Users in a reuse 1 system enjoy dynamic interference reduction from neighboring APs. At the same time, the benefit of reuse 2 system on improved user SINR cannot outbalance the deficiency of having its available frequency resource per user halved. Furthermore, the advantage of using reuse 2 is subject to great planning effort meanwhile the gain is marginal. We show also with finite buffer traffic, the superior performance of the proposed I-DS system and its robustness towards non-optimal AP placement. The gain achieved by I-DS over Femto system is even more obvious with finite buffer traffic, compared to previous results obtained with full buffer traffic presented in [9]. Regarding the poor performance given by SC-DAS system, in our future work we will examine the performance of multi-sector DAS, where spectrum could be reused spatially along with increased interference between APs belong to different sectors.

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