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Published in:
Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th

DOI (link to publication from Publisher):
10.1109/VTCFall.2013.6692289

Publication date:
2013

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Hu, L., Sanchez, M. L. L., Maternia, M., Kovacs, I. Z., Vejlgaard, B., Mogensen, P., & Taoka, H. (2013). Modeling of Wi-Fi IEEE 802.11ac Offloading Performance For 1000x Capacity Expansion of LTE-Advanced. In *Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th* (pp. 6). IEEE. I E E E V T S Vehicular Technology Conference. Proceedings https://doi.org/10.1109/VTCFall.2013.6692289

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Modeling of Wi-Fi IEEE 802.11ac Offloading Performance For 1000x Capacity Expansion of LTE-Advanced

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Abstract— **This paper studies indoor Wi-Fi IEEE 802.11ac deployment as a capacity expansion solution of LTE-A (Long Term Evolution-Advanced) network to achieve 1000 times higher capacity. Besides increasing the traffic volume by a factor of x1000, we also increase the minimum target user data rate to 10Mbit/s. The objective is to understand the performance and offloading capability of Wi-Fi 802.11ac at 5GHz. For the performance evaluation of Wi-Fi, we propose a novel analytical throughput model that captures both key 802.11ac enhancements and multi-cell interference. We provide a quantitative evaluation of large-scale indoor Wi-Fi 802.11ac deployment in a real urban scenario by extensive simulations. We conclude that deploying indoor Wi-Fi access points in almost every building is essential to carry the x1000 traffic volume and ensure a minimum user data rate of 10Mbit/s.**

I. INTRODUCTION

Mobile network operators are facing a critical challenge on how to deal with the anticipated mobile data explosion of 1000 times more traffic within the next 10 to 15 years [1] in a cost efficient way. Increased use of smartphones, tablets, netbooks and USB sticks with embedded HSPA (High Speed Packet Access)/LTE (Long Term Evolution) capabilities will be continuously taxing the mobile networks for scarce capacity resources. Fortunately, most of these portable devices also have embedded Wi-Fi access capabilities. To accommodate the high expected mobile traffic growth, industry and academia have started researching how to expand the network capacity: The capacity "cube" of improved spectrum efficiency, allocation of more spectrums at higher frequency and deploying more and smaller cells are generally anticipated as the methods to increase network capacity. Differences in views are more in the details of how much capacity gain is expected from each domain of the capacity cube [2][3]. On top of the x1000 traffic volume increase over the next 10-15 years, we also expect the minimum user data rate to increase by a factor of x10.

In practice our recent network evolution studies indicate that the most cost efficient network evolution will be a Heterogeneous Network (HetNet) configuration. Among the possible HetNet capacity enhancement paths, Wi-Fi offloading is becoming an essential and attractive ingredient: 1) Wi-Fi operates on excessive unlicensed spectrum (2.4GHz/5GHz band) and may provide great capacity enhancement at a much lower cost, compared to cellular-based small cell options (micro and pico cell) that operate on license band; 2) Wi-Fi has been a mature technology, and 2.4GHz Wi-Fi access support is embedded in most data enabled mobile devices e.g. smartphones, tablets and laptops. These form a very good basis for deploying advanced Wi-Fi offloading solution; 3) The Wi-Fi standard development is continuously evolving with IEEE 802.11n today being mainstream and the latest high capacity gigabit Wi-Fi solution IEEE 802.11ac [4] soon reaching the commercial market. Most important in the evolution is probably the support of the 5GHz ISM band unleashing approximately 400-500MHz of new spectrum for wireless usage.

In this paper, we provide a quantitative study on the potential role of indoor Wi-Fi 802.11ac deployment as a HetNet solution for a LTE-A network expansion to achieve 1000x more capacity. We base our study on a European City case study using existing macro sites, 3D-building models and spatial traffic measurements and modeling.

Our contributions are two-fold: firstly, we propose an analytical Wi-Fi throughput model that captures key 802.11ac features and multi-cell interference; secondly, we quantitatively study the performance and offloading potential of indoor Wi-Fi 802.11ac deployment to achieve 1000x more capacity. The remainder of the paper is organized as follows: Section II presents the 802.11ac modeling framework. Section III introduces the system model of deployment study including LTE-A network model. Section IV presents Wi-Fi deployment strategies. Section V provides performance results. Finally, Section VI concludes the paper.

II. IEEE 802.11AC MODEL

A. Key Features of Wi-Fi IEEE 802.11 ac

IEEE 802.11ac can be seen as a capacity evolution of IEEE 802.11n standard. 802.11ac supports medium access control (MAC) layer throughput of more than 500 Mbps for a single user scenario and aggregated MAC throughput of more than 1 Gbps for a multi-user scenario. Four basic notions are enhanced: wider channel bandwidths, higher-order modulation coding scheme (MCS), MAC support of dynamic channel width capability, and multi-user multiple input multiple output

(MU-MIMO). Compared to 802.11n standard, a wider bandwidth of 80 and 160 MHz is introduced in 802.11ac e.g. the 80 MHz mode uses two adjacent 40 MHz channels with some extra subcarriers to fill the unused tones between two adjacent 40 MHz channels. Also, two new MCSs 8 and 9 are introduced based on 256-QAM with coding rates of 3/4 and 5/6 for a further 20% and 33% improvement in a physical layer data rate respectively, compared to the highest MCSs 64-QAM with 5/6 coding rate of 802.11n. Thirdly, 802.11ac modifies the 802.11n MAC to address coexistence and medium access with the support of wider channels, where the station can dynamically adjust its channel bandwidth depending on its neighboring cell interference situation. Finally, 802.11ac introduces downlink MU-MIMO where an access point can simultaneously transmit data streams to multiple client stations.

B. Physical Layer Performance Model

We model the physical layer performance of 802.11ac by using signal to interference plus noise ratio (SINR) to physical throughput mapping curve. This curve is obtained by using exponential effective SINR method (EESM).

C. MAC Throughput Model

The achievable MAC layer throughput can be estimated by modeling 802.11ac distributed coordination function (DCF) under multiple Wi-Fi cells (or Basic Service Sets) coexistence scenario. Each station (STA) proactively contends the channel access with other stations and access point (AP) using the protocol of Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). The radio resource allocation is fully distributed and implicitly done by all nodes within the same cell following the same channel access protocol. It is node-centric in the sense that the AP has the same channel access chance as each STA. There are two essential aspects of modeling 802.11ac DCF function: 1) MAC efficiency: the distributed channel access of CSMA/CA leads to significant protocol overhead as well as collisions; The MAC efficiency measures the overall channel usage for actual data transmissions despite the overhead; 2) MAC Interference: neighboring co-channel APs and STAs generate strong interference so as to prevent the CSMA/CA-based channel access in current cell; In particular, a node is prevented from sending packets to other nodes when it receives interference signal from a neighboring transmitter with the received signal strength level (RSSI) larger than a sensing threshold. The MAC throughput of user *i* can be modeled as follows:

$$Tput_i = PHY_i \times RB_i \times (BW \times \eta_{MAC}) \qquad (1)$$

Where MAC efficiency: η_{MAC}, channel bandwidth: BW, spectrum efficiency of user *i*: PHY_i, radio resource share of user *i*: RB_i. The product of BW and η_{MAC} is the effective channel bandwidth despite the protocol overhead. BW and PHY_i are known parameters.

Firstly, MAC efficiency can be modeled by using method in [5]. Define MAC frame transmission time: T_{data}, ACK frame transmission time: T_{ACK}, back-off time: $T_{backoff}$ and the mean value of back-off time: $E(T_{backoff})$. SIFS (Short Inter-Frame Space) and DIFS (Distributed Inter-Frame Space) time intervals are defined as Wi-Fi standard. We assume that Aggregation-MAC Protocol Data Unit (A-MPDU) is the frame aggregation option with implicit block acknowledgement (i.e. ACK frame is equal to BA frame) [4]. We also assume that the MAC frame size is fixed and equal to the aggregated size by using MAC A-MPDU. MAC efficiency is:

$$\eta_{MAC} = \frac{T_{data}}{T_{data} + SIFS + T_{ack} + DIFS + E(T_{back-off})}$$
$$where$$
$$T_{data} = \frac{MAC\_Frame\_size}{PHY_{Ave}} \qquad (2)$$

PHY_{ave} is average PHY spectrum efficiency of all nodes including both STAs and AP.

Next, to derive RB_i in eq.(1), we assume the following: each user generates both downlink (DL) and uplink (UL) traffic at the same time, and there are N STAs in one cell; To model the asymmetry load of DL and UL, we assume that DL has full-buffered traffic model, whereas UL traffic has full-buffer model with an activity factor β (between 0 and 1). In other words, AP always has DL frames to transmit and always contends channel access, whereas each STA only contends channel access with a probability β to transmit UL frames. Assume that *M* neighboring APs and STAs create MAC interference to the serving Wi-Fi cell, they are modeled as *M* additional STAs in the same cell that contends for the channel access.

RB_i in eq. (1) can be derived by using a set of properties of CSMA/CA protocol [8] under full-buffered traffic model :1) In the long term, the UL and DL radio resource share ratio is $\beta \times N$ for each STA. When β =1, UL traffic has *N* times higher air interface time than the DL traffic at each STA, since AP only has the same air interface time as one STA, but it has to serve all *N* STAs by sending DL traffic; 2) In the long term, a set of STAs receive the same amount of DL data, independent of their spectrum efficiency. The same property applies to UL. STA with higher spectrum efficiency will occupy less air interface time than lower spectrum efficiency STA. Thus the set of STAs of the same Wi-Fi cell have the same average DL throughput in the long term, independent of their SINR; The same applied to the UL throughput; Define the MAC frame size to be a fixed value of *Pkt*, the overall DL throughput of STA *i* can be derived as follows :

$$Tput_i^{DL} = PHY_i \times \frac{\frac{Pkt}{PHY_i}}{(\beta \times N + 1)\left(\sum_{k=1..N} \frac{Pkt}{PHY_k}\right) + M \times \sum_{j=1,2...M} \frac{Pkt}{PHY_j}} \times (BW \times \eta_{MAC}) \qquad (3)$$

The UL throughput of STA *i* can be derived in a similar way.

D. Model Validation From System-level Simulation

The analytical MAC throughput model is validated via system-level 802.11ac simulations. We assume the following: it is a single Wi-Fi cell scenario; each STA has the same DL/UL SINR of 10.8 dB; channel access probability β is 1/20 and A-MPDU by aggregating 40 frames of 1500 bytes each; SISO antenna configuration with channel bandwidth of

20MHz. Fig.1 shows the DL and UL MAC throughput per STA *vs* number of STAs. The analytical model matches well the system-level simulation result as shown in fig.1. In particular, as the number of STAs increase, DL/UL MAC throughput scales down with the following factor:

$$\text{DL scaling factor:} \quad \frac{1}{N\times(\beta\times N+1)} \tag{4}$$

$$\text{UL scaling factor:} \quad \frac{1}{N+1/\beta} \tag{5}$$

Assume that β is constant, as N increases, DL throughput decreases much faster (in O ($N\times N$)) than UL throughput (in O (N))

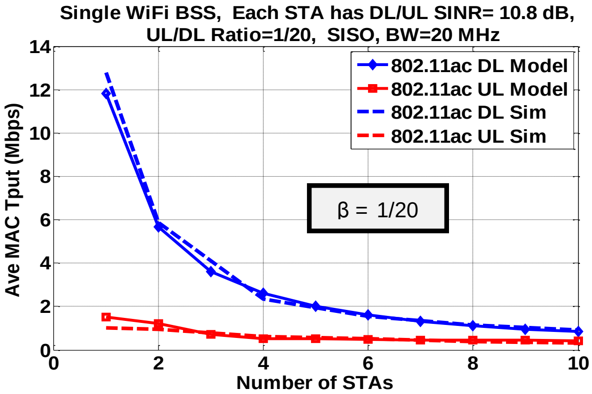

Fig. 1. 802.11ac MAC DL and UL Throughput

III. REAL DEPLOYMENT SCENARIO MODELING

A. LTE-A Network Layout & Building Database

The Wi-Fi 802.11ac deployment study has been carried out in a dense urban scenario with a deployed LTE-A network that is upgraded from the existing 3G macro site locations (described in [5][6]). The size of the investigated area is approximately 1 km^2, containing 4 three-sector macro sites with optimized antenna down-tilt and average inter-site distance of ~300 m. In addition, there are 40 outdoor micro cells deployed in traffic hotspot area to help offloading the macro cell. The number of micro cells deployed corresponds to the optimal number in terms of radio performance and cost, under practical constraints.

The real 3D building database of the investigated area is employed for modeling indoor area. The entire area of 1 km^2 contains 1000 buildings with 5 floors in average. The same cellular radio performance model as in [6] is employed. The LTE-A physical layer performance is modeled by a SINR-to-Physical_Throughput mapping curve that includes adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ) and multiple input and multiple output (MIMO) transmission up to 2x2 spatial multiplexing, whereas the user outage minimization scheduler is employed for radio resource allocation [5][6].

B. Spectrum Allocation

For the reference network setup, we assume that the several licensed spectrum bands used by current 2G and 3G network layers are re-farmed for our LTE-Advanced/4G-like network. In particular, each of the 12 LTE-Advanced macro cell sectors is assumed to employ 4 different carriers, operating in FDD (Frequency Division Duplexing) mode at 800 MHz, 900 MHz, 1800 MHz and 2100 MHz carrier frequency and use ideal LTE-Advanced carrier aggregation (CA) between the 800-900MHz bands and similarly between 1800-2100MHz bands. As the basic configuration, the micro cell layer is assumed to operate in the FDD 2.6 GHz band. In addition, the new 3.5GHz spectrum that is beyond International Mobile Telecommunications (IMT) spectrum [9] can be allocated to enhance the micro cell performance. We assume that the 3.5GHz spectrum is used in TDD (Time Division Duplexing) mode, since it gives more flexibility on both dynamic downlink/uplink traffic ratio and more flexible spectrum re-arrangement. We assume the TDD downlink/uplink ratio is 1:1. To further enhance the network capacity and indoor coverage, we look into the deployment of indoor Wi-Fi 802.11 ac APs operating at unlicensed 5 GHz band.

C. 3D Propagation Modeling

To accurately estimate path loss for macro and micro cells at outdoor locations, a 3-D ray-tracing tool is used. Outdoor to indoor path loss is predicted by using a 20 dB external wall loss plus a linear attenuation factor of 0.6 dB/meter for indoor internal wall loss [5][6].

The studied area was divided in square pixels of 10 x 10 meter, which are the basic unit for the performance modeling and evaluation [5][6]. In order to accurately model the indoor small cell deployment, the 3-D building footprint and its number of floors are considered in the modeling framework along with a statistical outdoor-to-indoor and indoor-to-indoor path loss models (following the description in [5][6]).

D. Network Key Performance Indicator

The selected network key performance indicator (KPI) is defined as the 90% service coverage for a given fixed minimum downlink user data rate, i.e. less than 10% outage. We estimate that the current minimum downlink data rate required for the subscribers to experience an 'acceptable' mobile broadband service is in the order of 1 Mbit/s [2]. We expect this minimum acceptable downlink data rate to reach 10 Mbit/s during the time frame of the 1000x traffic growth/ 1000x capacity demand [2].

E. Spatial Traffic Model & 1000x Traffic/Capacity Demand

The network traffic load is simulated in terms of the number of simultaneous active downlink users, which are randomly placed in the network area following a predetermined spatial user density map. This spatial user density map is derived from busy hour downlink traffic measurements in the existing 3G network. We have combined this measured spatial traffic data with an expected outdoor-indoor traffic split of 30-70% and a traffic distribution across the building floors with 50% of the indoor traffic generated at ground floor [5][6]. The relative spatial user density distribution is assumed to remain constant during the time period of the 1000x traffic growth.

By using our traffic forecast tool [7], the 1000x traffic/capacity demand is modeled in terms of an increased number of simultaneous active users downloading data in the network as follows:

- *280 simultaneously active downlink users with 10 Mbit/s minimum user data rate requirement.*

IV. WI-FI DEPLOYMENT STRATEGIES

This section describes Wi-Fi deployment in terms of traffic steering, multi-channel operation and access point placement.

A. Traffic Steering Methods

There are two options of the traffic steering between Wi-Fi network and LTE-A network: 1) Best-Server: the user is first connected to the Wi-Fi network if its SINR is larger than a certain threshold i.e. 5 dB; the user selects the AP that gives the best SINR; users are offloaded to Wi-Fi network as much as possible without considering actual user experience; 2) SMART: the user first connects to Wi-Fi network only if 1) *User SINR > threshold; 2) Estimated user throughput > minimum data rate.*

B. Multi-channel Operation

802.11ac operates on 5GHz unlicensed spectrum with 480MHz bandwidth. 802.11ac has the flexibility of configuring various channel bandwidth, i.e. increase the channel bandwidth by bonding multiple adjacent channels. The total 480 MHz spectrum can be channelized into various bandwidth options 20/40/80/160MHz, which result in 24/12/6/3 numbers of orthogonal channels that can be allocated to each Wi-Fi cell to mitigate inter-cell interference. The smaller the bandwidth, the larger number of orthogonal channels can be allocated to mitigate inter-cell interference. For the channel allocation, we assume a simple and efficient uniform channel assignment: each Wi-Fi cell is assigned one channel that is uniformly picked up from the channel pool.

C. Access Point Placement

Due to the expected high number of Wi-Fi APs involved, the AP placement algorithm is based on a simple traffic-driven deployment algorithm [5][6]. The main idea is that of sub-dividing the investigated area into spatial grids, sorting the aggregate traffic density of each grid, and finally deploying APs in the highest traffic density grids.

V. PERFORMANCE EVALUATION

In this section we provide the numerical results and the performance of indoor Wi-Fi 802.11ac deployment. Firstly, we study the Wi-Fi AP density and 3.5GHz spectrum allocation to outdoor micro cell in order to meet 1000x capacity demand. Secondly, we study various Wi-Fi deployment strategies i.e. traffic steering policies and channel bandwidth options, and identify the optimal configurations. The described modeling framework of Wi-Fi 802.11ac and LTE-A cellular network has been implemented in a MATLAB-based network planning tool including a static network simulator [5][6]. Table 1.1 and 1.2 introduce the simulation parameters of 802.11ac and LTE–A network. For 802.11ac, MAC payload size is assumed to be constantly 1500 bytes, and the A-MPDU of 5 MPDU is applied as frame aggregation option. The traffic model of Wi-Fi is full-buffered for both DL and UL where the UL activity factor β is 1/6. To model the practical Wi-Fi interference scenario, we assume that one operator deployed Wi-Fi network receives external interference from other three Wi-Fi networks owned by other mobile operators and deployed close, i.e. four Wi-Fi networks shared the unlicensed spectrum at 5 GHz band. Only SU-MIMO (single user MIMO) is modeled for 802.11 ac. The indoor Wi-Fi AP placement employs the traffic-driven algorithm described in section IV.C with the minimum inter-site distance (ISD) of 20 meters between APs, 20 meters to micro site and 50 meters to macro site. We assume open subscriber group (OSG) for Wi-Fi access. For LTE-A traffic steering, cell range extension (RE) is applied to offload more users to micro cell. This emulates the reference signal received quality (RSRQ) and cell range extension procedure supported in LTE-A.

Table 1.1: Simulation Parameters of Wi-Fi 802.11ac

Parameter	Setting
Wi-Fi TX power	20 dBm
Wi-Fi MAC Payload Size	1500 Bytes
MAC Frame Aggregation	A-MPDU with aggregation of 5 MPDU subframes
Wi-Fi Traffic Model	DL: full buffer, UL : full buffer with activity factor 1/6
MIMO configuration	2 x 2 SU-MIMO No support of MU-MIMO
Carrier frequency	5 GHz (total 480 MHz spectrum)
Channelization Bandwidth	40/80/160 MHz
Wi-Fi channel allocation	Uniform Random
Wi-Fi Traffic Steering Policy	SMART
Wi-Fi AP Placement	Indoor Traffic-driven deployment, min ISD 20m to other APs, 20m to micro cell, 50m to macro cell
Number of External Wi-Fi Networks	3 external Wi-Fi networks are deployed

Table 1.2: Simulation Parameters of LTE Network and Deployment Scenario

Parameter	Setting
Transmission Scheme	Downlink 2 x 2 MIMO (LTE-A)
Macro Carriers (FDD)	10MHz@800MHz, 10MHz@900MHz 15MHz@1800MHz, 15MHz@2100MHz
Micro carriers (FDD or TDD)	See Section III.B
Transmit Power （Per Carrier）	Macro: 46 dBm. Micro: 30 dBm,
Antenna Configuration	Macro: Real antenna pattern with down-tilt angles; Micro: 6 dBi real omni-antenna, antenna height 5 m;
Path Loss Model	Ray traced path loss for macro and micro cells Modified version of [8] for WiFi
Traffic Model	Full Buffer 280 active UEs @ 10Mbps min. data rate
User Distribution	Measured user density map (see Section II) 30%-70% outdoor-to-indoor user split 50% of indoor users located at the ground floor
Traffic Steering Policy	Micro : Range Extension with RSRQ bias of 3 dB

A. Wi-Fi 802.11ac Offloading & 3.5GHz Spectrum Allocation

Firstly, we study the feasibility of meeting 1000x network capacity demand by indoor Wi-Fi 802.11ac deployment complementing the LTE-A network. Fig.2 shows the user outage per layer for various Wi-Fi AP densities from 0, 500, 1000, up to 1500 AP/km when the minimum user data rate is 10 Mbit/s. Without any indoor Wi-Fi deployment, the network suffers from user outage of 20% that is far above the 10% KPI requirement, even if outdoor micro cell is deployed and 3.5GHz spectrum is allocated. Fig.3 shows the percentage of indoor and outdoor users in outage. The majority of user outage comes from the macro served users that are located inside the building area and also outside the coverage of outdoor micro cell. When 500 Wi-Fi AP/ km^2 are deployed in the indoor area, a significant improvement of user outage can be seen in fig.2, especially for indoor user outage from macro cell. The user outage drops from 20% to 9%, which is below the target maximum 10% user outage. Note that, by SMART traffic steering in section IV, the Wi-Fi layer has always "0" user outage. The increase of AP density from 500 to 1000 AP/ km^2 further improves the user outage. However, as the number of APs increase from 1000 to 1500, the Wi-Fi offloading gain saturates. To summarize, indoor Wi-Fi density of 500 AP/ km^2 (125 AP/macro site) can help the LTE-A network meet the 1000x capacity demand when the minimum user date rate is 10 Mbit/s provided that new 3.5GHz spectrum is allocated to micro cell. Fig.4 shows the percentage of users served at each layer at the same set of configurations in fig.2: indoor Wi-Fi deployment offloads traffic both from macro and micro cell: 500 AP/ km^2 offloads already more than 50% users; As the Wi-Fi density increases from 1000 to 1500 AP/ km^2, the offloading gain gradually saturates, i.e. from 65% to 69% users offloaded to Wi-Fi, because indoor Wi-Fi already offloads almost the upper limit of all indoor users that account for 70% of all users. Indoor Wi-Fi serves mostly only indoor users, but not outdoor users because the deep wall penetrations and low transmission power prevent Wi-Fi's outdoor coverage.

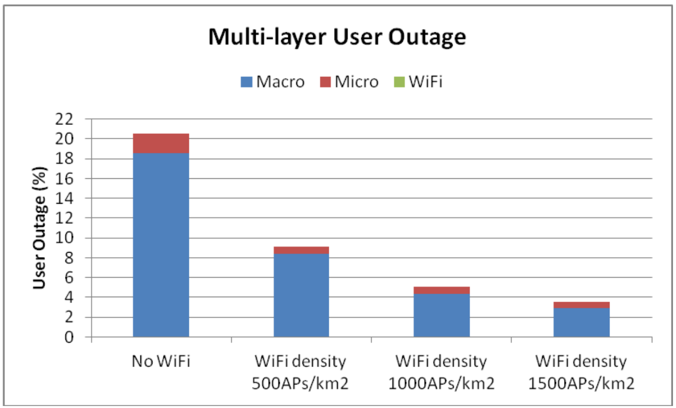

Fig. 2. User Outage vs. Wi-Fi Density/ km^2

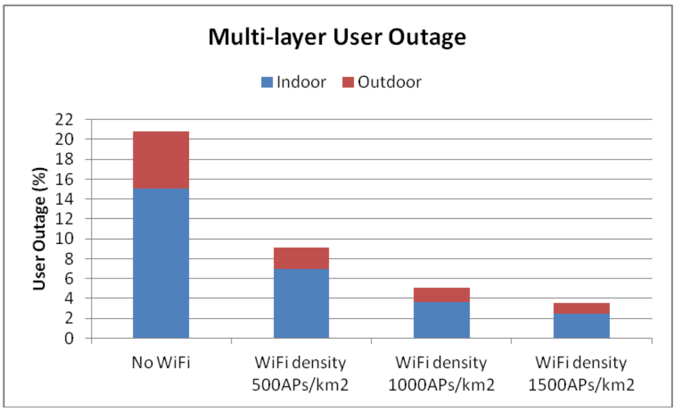

Fig. 3. Indoor/Outdoor Outage vs. Wi-Fi Density/ km^2

Secondly, on condition that new 3.5GHz spectrum is not available, can indoor Wi-Fi deployment still meet the 1000x capacity demand? Assuming that the deployed Wi-Fi density is 1500/ km^2 and the minimum user data rate is 10 Mbit/s, our simulation results show that the network achieves user outage of 4.8% which is far below the target maximum 10% user outage KPI. Due to the limited space of the paper, we do not intend to show the detailed results of this case.

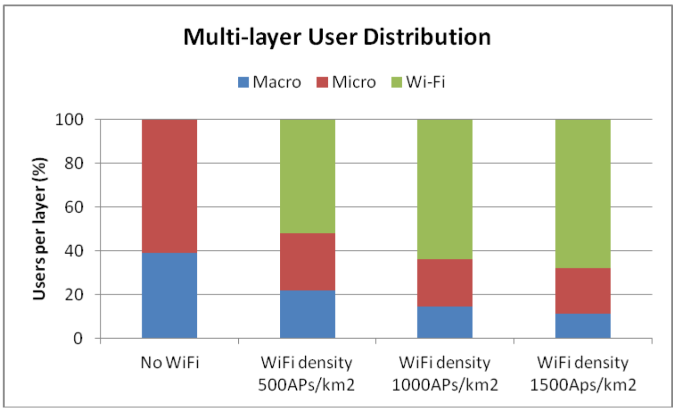

Fig. 4. User Distribution vs. Wi-Fi density/ km^2

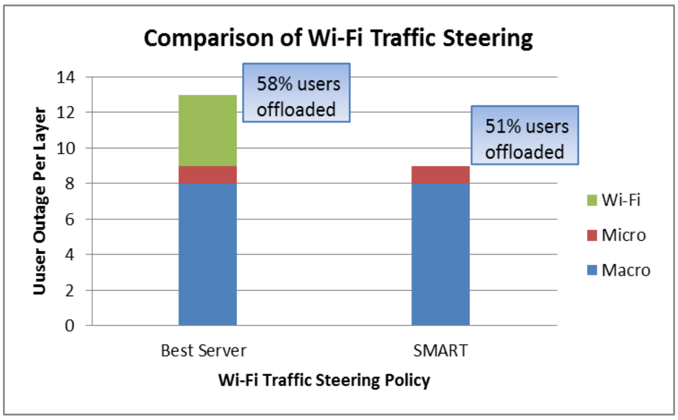

Fig. 5. Wi-Fi 802.11ac Traffic Steering

B. Impact of Wi-Fi Traffic Steering Policy

We compare two traffic steering policies - "SMART" and "Best-Server" as in section IV.A. Assume the same network configuration as above: user minimum data rate requirement is 10Mbit/s, Wi-Fi density is 500/km^2. Fig.5 shows the performance superiority of SMART in terms of user outage: with SMART, there is no user outage at Wi-Fi layer since there is a data-rate based user admission control, i.e. only users that can achieve the minimum data rate are admitted to Wi-Fi; however, with Best-Server, there is 4% user outage at Wi-Fi layer. The macro/micro layer performance is identical for the two traffic steering policies.

C. Wi-Fi Channel Bandwidth Options at 5GHz

We also study various channel bandwidth options of 802.11ac at 5GHz band. Due to lack of space, the results are not shown here. With 802.11ac, the channel bandwidth can be bonded to 40/80/160 MHz, whereas the number of orthogonal channels are 12/6/3 respectively. As stated in section IV.B, the uniform channel assignment is assumed. Interestingly, our results show that the network performance is not so sensitive to the bandwidth configuration: a bandwidth of 40 MHz gives only a slightly better performance than a bandwidth of 80 or 160 MHz. Even if a very large bandwidth can bring more capacity at one Wi-Fi cell, it sacrifices the overall spatial frequency reuse gain, i.e. less orthogonal channels can be allocated to neighboring cells, which lead to higher inter-cell interference, and fewer users can be offloaded to Wi-Fi due to the minimum SINR threshold.

D. Discussion on the Multi-Floor AP Deployment

We mainly study the Wi-Fi deployed on the ground-floor, since 50% UEs are assumed located in ground floor while UEs at higher-floor are already served by outdoor micro and macro cells. We are under an on-going study on the multi-floor deployment in scenarios where the traffic distribution is uniform vertical among floors and especially in scenarios where there are many high-rise buildings (e.g. 100 m above) with limited outdoor micro / macro coverage.

VI. CONCLUSION

We quantitatively study the indoor Wi-Fi 802.11ac deployment as the capacity expansion solution of LTE-Advanced to meet 1000x capacity/traffic with a target user data rate of 10Mbit/s or higher. For the performance modeling, we propose a novel analytical throughput model that captures both key 802.11ac features and Wi-Fi multi-cell interference. The model is well validated by detailed system-level simulations.

We conclude that Wi-Fi at 5Ghz will play an important role for the 1000x mobile network capacity demand. Deployment of outdoor micro cells certainly boost network capacity, but we still see high outage in providing the target user data rate of 10Mbit/s or higher. Deploying indoor Wi-Fi access point at 5GHz in each building offload up to 70% of the traffic from the cellular network, and improve significantly the indoor coverage and ensure very low outage in delivering a minimum user data rate of 10Mbit/s.

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