Attainable User Throughput by Dense Wi-Fi Deployment in Residential Zones at 2.4 GHz

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***Abstract*—Wi-Fi densification is a problem in cities and areas with high population density. Many access points still use the IEEE 802.11n Wi-Fi standard. This report looks at how network throughput is affected by the increase in network densification with a focus on the IEEE 802.11n standard and residential areas. It also includes a comparison of different channel frequencies. The result shows that more channels gives better throughput and that using a 40 MHz channel instead of two 20 MHz channels is preferred with throughput in mind.**

***Index Terms*—Wi-Fi, 2.4 GHz, IEEE 802.11n, Throughput, Densification, Residential.**

I. Introduction

WI-FI is today an increasingly popular network technology which supports devices in both homes, public environments, transportation and factories. With the introduction of Internet of Things the amount of devices in need of Wi-Fi is expected to rise exponentially. The free 2.4 GHz band is one of the most commonly used in different environments e.g. residential areas, offices, shopping malls, and it is used for a range of different tasks, e.g. Wi-Fi, Bluetooth and microwave ovens. As a Wi-Fi band it has better range than the newer 5 GHz band and is assumed to still be one of the most used frequency bands. The majority of people live in dense residential areas and are generally not prone to upgrade their routers and access points when a new standard is deployed. Especially since most home deployments are small and probably do not feel the need of greater throughput. This makes the 2.4 GHz band in this kind of area interesting to investigate, to see what the problems are today so they can be addressed in the future.

In our project we aim to quantify the attainable data rates and total capacity that can be supported by high density Access Point (AP) deployment in an area. We do this by calculating the mean area throughput at different deployment densities. We consider a simplified stochastic interference model for the modeling of the mean area throughput.

The goal of this project is to quantify the achievable user throughput of a dense deployment of IEEE 802.11n using access points in a dense residential area. We aim to answer the following questions:

- How are throughput of channels in 2.4GHz band affected by dense network deployments?
- Does the use of three 20MHz channels versus one 20MHz and one 40MHz channel affect the result?

To simplify the resulting simulation we made the choice to use a two dimensional environment as there would not make an important difference in the result but would benefit lowering the complexity. We also only simulate users and APs, disregarding any external sources of interference. To further lower the complexity of the simulation we use only non-overlapping channels as the advantage of using overlapping channels is not clear in a dense AP environment as our simulated scenario [1]. Lastly we use a probabilistic environment using WINNER II [2] rather than a predefined one. This has the consequence of making the directional propagation of the signals uniform rather than dependent on actual wall placement. But we figured that any scenario-specific result would disappear because of the way we intended to use random placement of everything over several runs and therefor we would get similar result with a probabilistic model.

The paper "Attainable user throughput by dense Wi-Fi deployment at 5 GHz" [3] covers a related study which looks into more environments than we intend to and focuses on 5 GHz instead of 2.4 GHz. We have taken great inspiration from this study.

The paper is organised as follows. Section II describes the scenario for which the simulation is built for. Section III describes how the simulation is built and the reason behind the choices. Section IV shows and explains the results. Section V present the conclusion based on our results.

II. Deployment Scenario

This section discuss our assumed environment and AP deployment strategy.

A. Scenarios and propagation models

We start of by choosing what kind of scenarios to use for AP deployment. We want to compare the conditions in three different common environments for Wi-Fi deployment. For these three we chose the inside of a residential apartment building, the inside of a shopping mall, and direct Line of Sight (LoS) as our deployment environments. As for the AP placement, we placed them randomly inside the specified area with a minimum distance of 1 meter from any other APs that are already placed. All scenarios cover a square area $\mathbf{A}$ with a side length of 100 meters, and with an average wall density α, and mean attenuation L_w, which are dependant on the type of environment the area belongs to.

We continue with how to calculate the propagation of signals. This is something which is heavily dependant of

TABLE I
PARAMETERS FOR LOCAL ENVIRONMENTS

Local Environments	**Average wall density $\alpha(m^{-1})$ [4]**	**Mean attenuation per wall L_w (dB)**
LoS	0	0
Home	0.231	5
Shopping Mall	0.047	12

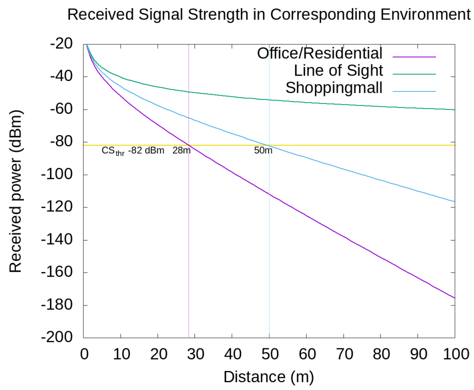

Fig. 1. Received power over distance with area types Line of Sight, Residence and Mall environments for comparison.

the specific environment the signal propagates through, and tracing of the electric fields in a specific environment quickly get compute intensive when in an environment with multiple objects where fields can pass through. To make this less compute intensive, we choose to use the WINNER II path loss model [2], which can be seen here:

$$L_{ij} = 46.4 + 20log_{10}(d_{ij}) + 20log_{10}(\frac{f_c}{5}) + n_w L_w(dB) \quad (1)$$

where d_{ij} represent the distance between two points, and f_c represent the frequency at which the transferred signal is centered, and $n_w = \alpha * d_{ij}$ represent the average amount of walls, as a simplification of a signals propagation in a specific environment.

B. Frequency Channel Availability in 2.4GHz

The regulations about license exempt radio bands change from region to region, but in a majority of the world frequencies between 2.401 GHz and 2.473 GHz are available to be used in Wi-Fi networks. This leads us to having three different non-overlapping channels with a bandwidth of 20MHz available in the 2.4GHz band for Wi-Fi usage, when using an Orthogonal Frequency-division Multiplexing (OFDM) encoded Physical (PHY) standard. The total aggregated bandwidth available in an area for Wi-Fi traffic is thus 60MHz which can be divided between either three 20MHz channels, or one channel using 40MHz, and one channel using 20MHz bandwidth, when making use of a PHY standard 802.11n [5] or a future standard i.e. 802.11ax which was not yet finalized as of writing this report.

III. SYSTEM MODEL

Here we model interference and momentary data rate allowed by a Carrier-sense multiple access with collision avoidance (CSMA/CA) policy, and provide a quantifiable measure of performance for downlink traffic, which is the most heavily utilized traffic direction for wireless networks. This we measure in average available Mbps/m^2.

A. Simulation Model

In a CSMA/CA 802.11 there exist multiple components to abstract the medium access, and to optimize protocol capacity,

- Predefined multiple channels
- Physical carrier sensing
- Binary exponential backoff
- Data rate adjustment to signal quality

1) Transmission specifications: Here we model these features for a performance evaluation of dense Wi-Fi deployment. As an interference mitigation method, we assume existence of K non-overlapping channels which belong to a set κ with bandwidth $w^k = \frac{W}{K}$(MHz). Let a set of APs operating in a specific frequency channel k be A^k. Each transmitting AP transmits with a power $P_t = p_t \cdot w^k$(dBm), where p_t (dBm/MHz) follows the regulation PSD limit that channel k belongs to. IEEE 802.11 specifies a fixed mandatory CS_{thr} for co-existing between anonymous Wi-Fi APs in unlicensed bands. For OFDM the limit is $10^{-8.2}$ mW for a 20MHz bandwidth channel. In each frequency channel, before transmitting, an AP compares the currently sensed signal with CS_{thr} (mW), ensuring no collisions, and then start transmitting. The Carrier Sensing range of an AP we refer as D_{cs} such that $L_{ij}(D_{cs})P_t = CS_{thr}$. D_{cs} (m) in different environments can be seen in Figure 1.

2) Set of active transmitters: If we define the set of APs belonging to a specific frequency channel k as A^k, then we can refer to all APs closer than D_{cs} of AP i as A_i^k. We express this mathematically as $A_i^k := \{x \in A^k, x \neq i | g_{ix}Pt > CS_{thr}\}$. We make the assumption that all APs within A_i^k perfectly detects an active AP, thus preventing signal collisions within D_{cs} from AP i. The active APs in a specific frequency channel k at a given time is referred to as $\phi^k \subset A^k$. The actively transmitting APs ϕ^k are important for the signal quality in a Wi-Fi network, and therefore we need a good estimate for it which is simple to calculate. An approach based on simulating the transmissions is guaranteed to capture the variable wall loss effect.

B. Stochastic Simulation

For us to model the random set ϕ^k we make use of a Simple Sequential Inhibition (SSI) process [6]. We define a SSI process ψ in a constructive manner on our finite and discrete set A^k. $\psi(n)$ consists of n random APs denoted $X_1, ..., X_n$ which are independently and uniformly distributed in our set A^k. Initially X_1 is added to $\psi 1$. Then X_i is added to $\psi(i)$ systematically, if and only if it does not belong to the contention domain of any APs in ψ, i.e., $X_i \notin \cup_{X_j \in \psi} A^k_{X_j}$

IV. RESULTS

Figure 2 shows the result from a run of the Monte Carlo simulations AP creation and user placement. Here one can

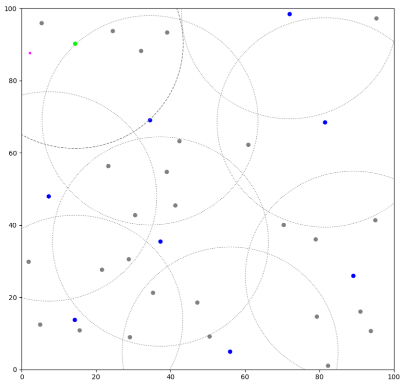

Fig. 2. Simulated transmitting range of the Access Points.

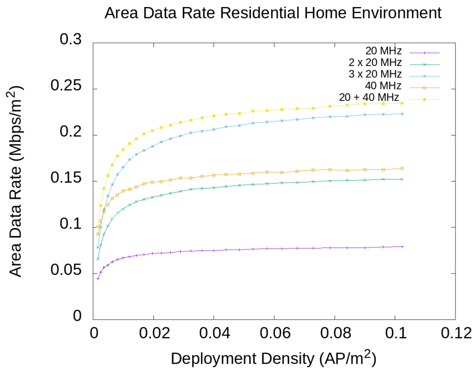

Fig. 3. Possible data rate using one, two or three channels.

see the APs as larger dots and the users random placement as smaller dots. The transmission range used in the simulation is also shown and how the interference from different APs overlap. Figure 3 shows the result of the simulation in the form of the predicted data rate of different number of channels over deployment density. Here we can also see the difference between using 40 MHz or 20 MHz channels. Lastly Figure 4 shows how the throughput scales per user given a 40 MHz and 20 MHz channel configuration for maximum total throughput.

V. Conclusion

We wanted to measure available throughput in the down-link over Wi-Fi in different environments, with dense deployment of APs in the 2.4GHz band. Furthermore we wanted to know what combination of channels would lead to the highest throughput being available.

From our results, we can learn that for the simulated environments the maximum throughput over an area was 0.2346 Mbps/m^2. This was achieved in the home environment, which had the highest attenuation from walls. Therefore we can conclude that a higher signal attenuation allows for higher total area throughput in our simulated environments.

Furthermore the highest throughput in the down-link was achieved with a channel configuration of one 20 MHz, and

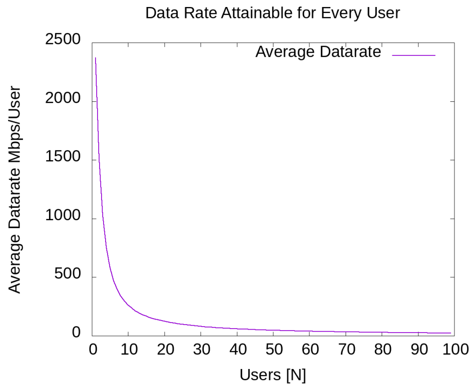

Fig. 4. Maximum throughput available for each user

one 40 MHz channel. Therefore we can conclude that for maximum throughput this channel configuration is the most suited for our simulated environments.

When looking at the simulated transmission of APs. We can see that full coverage of the area is achieved with most of the APs in a non-transmitting state. Those could perhaps be used for efficient AP placement in environments similar to our simulated ones.

For our LoS environment simulations, the attenuation was too low for more than one AP to transmit at the same time in the same channel. Thus no real conclusions can be deducted from the LoS environment, and further research would be needed to say anything about it.

References

[1] P. Miklavčič, "On the number of non-overlapping channels in the ieee 802.11 wlans operating in the 2.4 ghz band," *Elektrotehniski Vestnik/Electrotechnical Review*, vol. 81, pp. 148–152, 01 2014.

[2] Pekka Kyösti, Juha Meinilä, Lassi Hentilä, Xiongwen Zhao, Tommi Jämsä, Christian Schneider, Milan Narandzić, Marko Milojeviić, Aihua Hong, Juha Ylitalo, Veli-Matti Holappa, Mikko Alatossava, obert Bultitude, Yvo de Jong, and Terhi Rautiainen, "IST-4-027756 WINNER II d1.1.2 v1.2 WINNER II channel models."

[3] D. H. Kang, K. W. Sung, and J. Zander, "Attainable user throughput by dense wi-fi deployment at 5 ghz," in *2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*. IEEE, 2013, pp. 3418–3422.

[4] M. Unbehaun, "On the design and deployment of low-cost wireless infrastructure," phdthesis, Tekn. högsk., 2002.

[5] IEEE, "Ieee standard for information technology–telecommunications and information exchange between systems local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications," *IEEE Std 802.11-2012 (Revision of IEEE Std 802.11-2007)*, pp. 1–2793, 2012.

[6] T. V. Nguyen and F. Baccelli, "On the spatial modeling of wireless networks by random packing models," in *2012 Proceedings IEEE INFOCOM*, March 2012, pp. 28–36.