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Toward Dimensioning Cooperative High-Density Wireless Networks

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***Abstract*—The planning procedure of 802.11 WLAN networks is specific to each type of venue. In the case of large venues with high number and dense Wi-Fi devices, the network planning requires a deep investigation on: available channels, number of devices to associate, throughput per channels, etc. In addition, the WLAN planning of dense Wi-Fi devices becomes more complicated when adding collaboration between devices. The collaboration between devices is achieved by forwarding and sharing data through neighboring devices, named relays. In this paper, we provide guidelines for WLAN planning in high-dense collaborative environments. In addition, we study the network performance gains when content is distributed in cooperative manner through both unicast and multicast mode. Results show that using cooperative content distribution in dense environments leads to notable gain in network performance.**

***Index Terms*—Cooperative Networks, Multicasting, WLAN planning, Wi-Fi Direct.**

I. INTRODUCTION

Planning a Wireless Local Area Networks (WLAN) can be coverage-oriented or capacity-oriented. Coverage-oriented networks give more importance to the covered area than to the number of connected devices. The main objective of coverage-oriented networks is to increase the probability that a user will be able to reliably connect to an Access Point (AP) from any location within the network. In the case of capacity-oriented planning for high density (HD) environments, the access point should provide a target bandwidth per device to a high number of devices in a limited geographical area. WLAN planning in dense environments requires specific design considerations in order to support a large number of wireless devices. For example, HD large venues demand very high capacity and therefore far more APs than would be required for a strictly coverage-oriented model. Authors in [1] have investigated 802.11a Wi-Fi and LTE small cells deployments in a stadium environment. The outcome of their simulations is that the use of small cells deployment can increase the spectral efficiency, and thus satisfy the high capacity demand.

Networking companies have provided guidelines for WLAN planning for HD environments [2][3][4]. Nonetheless, none of these guidelines have considered studying the impact of cooperative devices on the network planning and its performance. In addition, they recommend avoiding the use of the multicast mode for data transmission. In fact, multicast frames are not positively acknowledged. As a consequence, data transmission will experience a relatively high packet loss rate, and thus a degradation of the quality of service at the end user. This is a serious problem for video streaming services, where loss of even a single packet can result in an error that propagates for many video frames. In addition, 802.11 WLANs suffer from the well-known rate anomaly problem [5], which can drastically reduce network performance (the rate anomaly problem is described in detail in Section III). For multicast transmissions, the goal is to reach all associated clients that can reliably receive multicast packets. Consequently, the data rate of a video stream, for instance, would be constrained by the environmental considerations of the least reliable receiver associated with the AP. Common solutions to address multicast challenges include implementing application layer retransmission mechanisms to deal with packet losses [6], in addition to possibility changing a multicast transmission to multiple unicast links in scenarios with high level of interference [2]. The big challenge with video streaming in unicast mode is scalability. Delivering the same video content to multiple devices in a unicast mode can easily overload the bandwidth and thus significantly decrease the per-device throughput. Other more advanced solutions that are applicable to dense environments include dynamic clustering of multicast groups based on network conditions, hybrid multicast/unicast solutions, and efficient group based retransmission schemes. In fact, in dense environments, there are many mobile users in close vicinity with respect to each other and, thus, can collaborate on high rate device-to-device links [7][8]. In addition, it is common for neighbor users to be interested in the same multimedia content as users are normally participating in a given event. Authors in [9][10][11] proposed a relay-based approach to improve the performance of WLANs, but they do not take into account the impact of relays on the WLAN planning.

In this paper, we provide a step-by-step guideline for cooperative HD WLAN planning, and we detail how a user device can be used as a relay for both unicast and multicast data, in order to optimize network planning and increase the network performance.

The remainder of this paper is structured as follow. A planning guideline for HD WLANs is detailed in Section II. The sub-section II-A gives an overview of the advantages of the IEEE 802.11ac protocol, and its utility for increasing HD network performance. In Section III, we first detail how to take into account the cooperative aspect of devices in the planning procedure, and how to estimate the throughput in both unicast and multicast modes. Section IV concludes the paper and outlines future works.

II. PLANNING GUIDELINES FOR HD ENVIRONMENT

Several steps need to be followed in order to make an appropriate HD WLAN planning. The first step to make for HD planning is the choice of the 802.11 protocol: 802.11n or 802.11ac or both.

A. Advantages of 802.11ac for dense WLANs

Most of the current works on IEEE 802.11 focus on increasing transmission speeds and range, improving Quality of Service (QoS), and adding new capabilities. In 2014, the IEEE 802.11ac amendment was released. It extends earlier 802.11 specifications, including 802.11n, and provides backwards compatibility with previous 802.11 specifications. This amendment includes mechanisms to improve the data throughput of existing WLANs and to handle the increasing number of devices that need to use a wireless network at faster speeds. For instance, 802.11ac specification provides a higher client capacity than previous 802.11 specifications and almost triples the bandwidth offered by 802.11n. This increase in capacity is only assured if enough non-overlapping channel frequencies are available for complete coverage of the denser layout.

The 802.11ac specification operates only in the 5-GHz frequency range, as opposed to the 802.11n spec, which operates in both 5-GHz and 2.4-GHz ranges. 5-GHz band is better than 2.4-GHz band for dense AP deployments, as it provides more non-overlapping channels and a higher channel reuse factor. Many newer Wi-Fi clients are dual-band enabled. But there are always older 2.4-GHz clients to deal with. When planning a WLAN, the use of 802.11n APs should be considered in order to connect devices which do not support 802.11ac or cannot work on 5-GHz spectrum. In the context of a dense environment, both protocols should be used, but it is more suitable to connect the highest possible number of Wi-Fi devices to 802.11ac APs, and benefit from its high quality performance.

B. Channel count

An important step for capacity planning is to count the number of usable channels in the HD environment. 802.11ac works only on 5-GHz spectrum. It has 23 non-overlapping 20 MHz channels for use, of which 14 require the use of Dynamic Frequency Selection (DFS) to protect radar operations. The 802.11n protocol can use three non-overlapping 20 MHz channels at 2.4-GHz spectrum.

The number of usable channels at 5-GHz depends on the country regulation. If we assume that the premises are located in a country that allows the use of 20 channels at 5-GHz, then the total count of usable channels is 23 (20 channels at 5-GHz plus 3 channels at 2.4-GHz).

C. Radio spectrum reuse

The radio spectrum reuse factor is the number of devices that can use the same channel at exactly the same time, without interfering with one another. In other words, the reuse factor is the frequency with which a single channel can be used again by other APs without causing co-channel interference.

Using a higher reuse factor will increase both the WLAN capacity and the total system throughput. When planning WLAN for HD area, it is recommended to increase the radio spectrum reuse by using APs with directional antenna and a small coverage.

D. Total system throughput

One metric that might be important to evaluate needed resources in WLAN is the Total System Throughput (TST). The TST depends on the number of usable channels C, the average good-put achievable in one channel by a mix of devices T, and the number of radio spectrum reuses R.

$$TST = C \times T \times R \tag{1}$$

For instance, if we consider 20 channels at 5-GHz, an average channel throughput of 30Mbps and a reuse factor equal to 4, then the TST at 5-GHz is equal to 2400Mbps. Increasing the reuse factor should be considered in order to obtain a higher TST.

E. Multi-client throughput

When multiple devices are simultaneously active in a cell, contentions, collisions, and Medium Access Control (MAC) layer overhead will reduce the medium capacity. Table I describes the impact of increasing number of simultaneous 802.11ac devices on per-device throughput [2]. Results show that the throughput decreases when more clients are added by an average of 20% with 50 simultaneous devices, and up to 60% for 100 simultaneous devices. If we consider a HD environment (Arena/Stadium), i.e. 100 concurrent active devices per channel, with a mixture of single and double spatial streams, then the unimpaired throughput of the channel will be estimated at 40Mbps.

A wireless channel is subject to several impairments, mainly co-channel interference and non-Wi-Fi interference. Therefore, an impairment factor has to be defined and applied to the unimpaired channel performance measurement. The impairment factor should be different for 2.4-GHz and 5-GHz bands, because 2.4-GHz band is more subject to interference than 5-GHz band. Based on the recommendation from [2], impairment factor in a dense environment should be 50% at 2.4-GHz and 25% at 5-GHz. When applying these impairment factors to the obtained unimpaired throughput at the previous

TABLE I
THROUGHPUT OF SIMULTANEOUS 802.11AC DEVICES (SINGLE SPATIAL STREAM)

Simultaneous clients	10	20	30	40	50	75	100
Aggregate throughput (Mbps)	60	55	50	45	40	32	26
Per-device throughput (Mbps)	6	2.9	1.8	1.2	0.9	0.4	0.2

step, the impaired good-put is approximately equal to 20Mbps at 2.4-GHz and 30Mbps at 5-GHz.

F. Key Performance Indicators (KPI)

For an efficient HD WLAN deployment, an accurate estimation of several KPI have to be estimated. KPI's estimation should take into account the premises type, the type of the event, users' applications and users' profiles. A bad KPI estimation will result in poor WLAN performance. For instance, if a stadium provides limited services on its network, then guests will concentrate on the game and merely use the network for a limited time, but if the stadium provides real-time and interactive services (scoring, replay, video streaming etc.) then the number of simultaneous active devices will be much higher. Table II describes the dimensioning key metrics for HD WLAN planning. KPI values in Table II are limited to guest seats (we assume that all guests own 802.11ac capable smartphones).

G. Clients per AP radio

In order to estimate the maximum number of concurrent device per channel (denoted χ), we need to estimate how much airtime the target application will consume when used on each device. The airtime is measured by dividing the required per-device throughput by the maximum achievable throughput per radio. The maximum number of concurrent (simultaneously transmitting) clients per AP radio to meet channel capacity is then computed using the formula 2.

$$\chi = \frac{1}{airtime} \tag{2}$$

TABLE II
KPI DEFINITIONS FOR DENSE PREMISES

Metric	Definition	Value
Take rate (denoted ρ)	Percentage of seating capacity with an associated Wi-Fi device	70%
Duty cycle (denoted η)	Percentage of one period in which Wi-Fi device is associated and active	70%
Average devices per person	Number of enabled Wi-Fi devices carried by one person/seat	1
Target Per-device good-put	The minimum allowable per-device bandwidth when multiple users are attempting to use the same AP	500 Kbps for Video playback
2.4-GHz / 5-GHz split (denoted $\delta_{2.4}$ and δ_5 resp.)	Distribution of clients across the two bands	25% / 75%

For instance, a required per-device good-put of $0.5Mbps$ and a maximum achievable TCP throughput (per-radio) of $30Mbps$ yields an airtime consumption of 1.66%. If we assume that all devices have similar characteristics (i.e. they consume similar airtime), then every device, running the defined application type, requires 1.66% of the capacity of a single access point radio. Thus, the maximum number of concurrent devices per AP radio is 60 devices.

H. AP count

The required number of AP radios to meet the number of active clients is deduced by dividing the total number of concurrent devices within the premises by the obtained number of concurrent devices per AP radio (Formula 2).

$$\begin{aligned}\text{AP Count at 5-GHz} &= \frac{\text{Total concurrent devices at 5-GHz}}{\chi} \\ &= \frac{\psi \times \rho \times \eta \times \delta_5}{\chi}\end{aligned} \tag{3}$$

In the case of a premises with 60000 seats, a take rate ρ of 70%, a duty cycle of 70% and a maximum number of concurrent devices per AP χ equal to 60, then the total number of required AP radios for the premises at 5-GHz (δ_5 is equal to 75%) is calculated as depicted in the formula 3 and is equal to 368 AP radios. The latter is the minimum number of required AP radios in order to fulfill the per-device airtime requirement. Similar approach is used to measure the required number of AP radios at 2.4-GHz.

The total number of AP can be divided by 2 if dual-radio APs are used.

I. Discussion

As detailed in previous sections, the required number of APs is highly dependent on the per-device throughput and the estimation of the duty cycle parameter. Nowadays, an acceptable end-user experience (web browsing, video streaming, VoIP calls, etc.) requires a minimum of 0.5Mbps. This minimum is hardly achievable in HD environment if there are limited number of usable channels and no optimization during the WLAN planning. In the case of a high duty cycle, a possible solution to increase the per-device throughput is to try to increase as much as possible the reuse factor (described in Section II-C), by minimizing cell sizes. There are several ways to minimize the cell size: (1) Limiting supported rates (2) Managing the power of the radio's (AP and Client) (3) Using the right antenna patterns to shape cell size. Properly dimensioning the cell size will maximize channel reuse in a limited space. Another possible solution to reduce the required number of APs and to increase the per-device throughput is to take advantage of the high density of Wi-Fi devices and new device-to-device technologies in order to facilitate cooperative content distribution. Authors in [1] made some simulations to study the efficiency of Wi-Fi and LTE small cells in dense environment like stadiums. Nonetheless, the study was limited to Wi-Fi 802.11a, and they didn't use any device-to-device

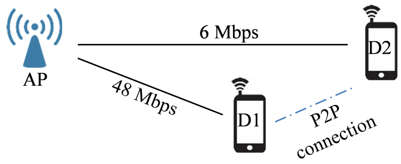

Fig. 1. Multicasting rate anomaly and device-to-device connectivity

communications. In the next section, we detail our proposed solution, and explain how to adapt WLAN planning in the case of cooperative content distribution.

III. WLAN PLANNING WITH COOPERATIVE CONTENT DISTRIBUTION

To optimize the network performance in HD environment and to resolve the rate anomaly when multicasting traffic, we suggest to use some client devices as relays. Figure 1 depicts relay use case and the rate anomaly. Due to multicasting, device $D1$ suffers from a bit rate as low as device $D2$, despite the fact that $D1$ has a good transmission bit rate with the AP. The proposed solution consists of using $D1$ as a relay for $D2$. In such way, only $D1$ will be connected to the AP, and $D2$ will connect to the network through $D1$. $D1$ will then fully benefit from its good connectivity with the AP, and $D2$ will profit from its proximity to $D1$ and will have a better transmission bit rate compared to when it was directly connected to the AP. The second benefit of this topology is that the AP will be able to serve many more devices than the usual use case. In fact, a relevant number of Wi-Fi devices will be handled by relays, and consequently the capacity of an AP can be significantly increased. In the recent years, new efficient device-to-device technologies were proposed and can be used for data transmission between neighbor devices. Wi-Fi Direct, described in Section III-A, is one of the best candidates that offer an easy way to automatically discover nearby devices and connect to them. The possible drawback for devices playing a role of relay is that their power consumption will be higher than in the normal case, due to the increased time spent in receiving and forwarding packet.

A. *Wi-Fi Direct*

Wi-Fi Direct (WFD) technology [12], also named Wi-Fi Peer-2-Peer, is a device to device solution developed by Wi-Fi Alliance. The WFD technology is built upon the IEEE 802.11 infrastructure mode. As a consequence, the WFD technology inherits all the enhanced QoS, power saving, and security mechanisms from the Wi-Fi infrastructure mode.

When using the WFD technology, devices are able to connect directly to each other in order to transfer content and share applications quickly and easily, without having to go through an AP, as it is traditionally the case. In addition, legacy devices (non-WFD devices) can join a WFD network, since the WFD device will have the requisite soft AP.

B. *Transmission rate in HD environment*

The required throughput at an AP depends on whether users are consuming unicast or multicast streams. In this section, we formulate the throughput estimation in both transmission modes. We consider that devices are divided into two sets: relay-capable and non-relay-capable devices. We assume that relay-capable devices are limited to nodes with direct connection to the AP (single-hop and no multi-hop). In addition, we consider that all nodes are single-radio, i.e., no simultaneous transmission over different channels. We denote by r_{ij} and t_{ij} the transmission rate and the throughput respectively from node i to node j.

The transmission rate r_{ij} to each device j depends on the capability of both devices i and j and on the distance from the transmitter i to the receiver j. The transmission rate per channel use, in an additive white Gaussian noise channel, is given by Shannon's theorem:

$$r_{ij} = \log_2(1 + SNR) = \log_2\left(1 + \frac{P_r(i,j)}{\sigma^2}\right) \tag{4}$$

where SNR is the received signal-to-noise ratio, $P_r(i,j)$ is the received power at node j from node i and σ^2 is the thermal noise power at the receiver.

The received power $P_r(i,j)$, can be linked to the transmitted power $P_t(i)$, by a path loss model as follow:

$$P_r(i,j) = \kappa \frac{P_t(i)}{d_{ij}^{\alpha}} \tag{5}$$

where κ is a unit-less constant that depends on the antenna characteristics and the average channel attenuation, α is path loss exponent and d_{ij} is the distance between the transmitter i and the receiver j. r_{ij} is then expressed as follow:

$$r_{ij} = \log_2\left(1 + \kappa \frac{P_t(i)}{d_{ij}^{\alpha}\sigma^2}\right) \tag{6}$$

As described in [13], boundary region of the network is the largest region of coverage. Almost 80% of the network coverage area is in the three lowest rate regions. Due to the lower signal strength at the boundary region, clients are constrained to use lower modulation schemes, resulting in inefficient use of bandwidth.

When using the appropriate modulation coding scheme, network overhead and network impairments have to be applied to the transmission rate in order to obtain an estimation of the received throughput at the application layers. In fact, the maximum achievable throughput at the application layers depends on the overhead caused by the used protocol at lower network layers. Based on the recommendation from [2], when using 802.11ac in dense environment, overheads of 25% for TCP/IP (+MAC) protocol and 20% for UDP (+MAC) protocol should be applied. The percentage of network impairments is basically the percentage of packet loss due to collisions and interference. The impairment factor depends on the venue, the density of active Wi-Fi devices and the Wi-Fi band (2.4-GHz or 5-GHz).

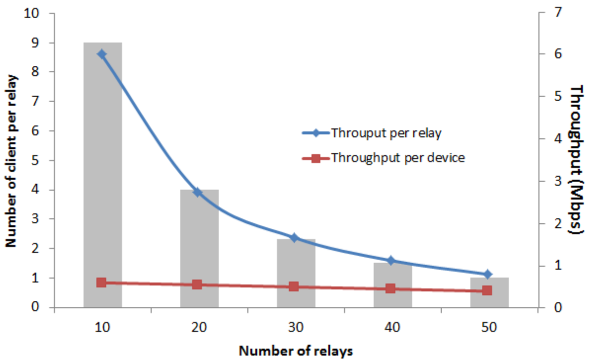

Fig. 2. Per-device and per-relay throughput

1) Throughput in unicast mode: In the case of unicasting, APs have to transmit the required content (sometimes the same) to each node separately. The per-device throughput highly depends on the number of nodes trying to simultaneously transmit/receive data at the AP. Examples of per-device throughput are depicted in Table I. In fact, increasing the number of simultaneous active devices in a cell results in reducing the medium capacity due to the growth of network impairments like contentions, collisions and MAC-layer overhead. For example, in the case of 75 simultaneous active (transmit/receive data) nodes on a 20 MHz channel offering a throughput of 65Mbps, the per-device throughput will be limited to 0.4Mbps.

In case we consider using relays, the number of simultaneous active relays should be reduced, so that the amount of network impairments can be reduced. The issue is to find out the optimal role distribution of devices: whether to directly connect to an AP and act as a relay or connect to a relay and act as a simple client. Figure 2 represents the distribution of 100 devices between the two roles and shows the per-relay and per-device (connected to relays) throughput. The x-axis represents the number of possible relays (out of 100 of total devices connected to an AP), and the left y-axis is the number of clients connected to each relay (represented by bars). The right y-axis represents the per-device and per-relay throughput. The per-relay throughput line is a representation of Table I, and the per-device throughput is deduced from the per-relay throughput and the number of clients per relay. Figure 2 confirms that the aggregated throughput of the 100 devices (relays and non-relays) decreases when the number of relays increases. For example, when there are 10 relays simultaneously receiving data from the AP (9 clients connected to each relay), the per-relay throughput is estimated at 6Mbps, the per-client throughput is almost 0.6Mbps and the aggregate throughput is nearly 60Mbps. Meanwhile, when 50 relays are simultaneously receiving data (1 client per-relay), the per-relay throughput is equal to 0.8Mbps, the client throughput is merely 0.4Mbps and the aggregated throughput is nearly 40Mbps. We can conclude that the use of a limited number of relays offers a good per-relay throughput, and thus a better per-client throughput. The selection of devices' roles can be based on the signal strength, and their proximity to the AP. If devices are uniformly distributed through the AP coverage, then almost 20% of the AP coverage is served with high signal quality. The AP should disable low data rate so that only devices with high data rate can associate to it. Therefore, 10 to 20% of associated devices to an AP should act as relays, and the rest of devices should act as simple clients and connect to relays.

The count of required APs in the unicast mode, with the use of relays is similar to formula 3. The difference is that the total number of devices that should associate with APs is limited to relays, and the other devices should connect to relays. If we consider using μ as percentage of device acting as relays then the required number of APs is as follow:

$$\text{AP Count at 5-GHz} = \frac{\psi \times \rho \times \eta \times \mu \times \delta_5}{\chi_{relays}} \tag{7}$$

We remind that ψ is the total number of devices, ρ is the take rate, η is the duty cycle of devices and δ_f is the percentage of devices in the band f. χ_{relays} is the number of concurrent relays connected to an AP. To compare with the example in Section II-H, we consider using μ=10% as the percentage of relays. The number of relays per AP radio χ_{relays} is equal to 6 in the case of 30Mbps good-put channel and a per-relay good-put of 5Mbps. Then the number of required AP radios is equal to 368 at 5-GHz. There are no difference on the number of required APs in the case of video streaming in unicast mode compared to the case where no-relays were used. Nonetheless, the reduction of the number of devices per AP radio permits the decrease of network contentions and collisions and thus an improved medium capacity.

2) Throughput in multicast mode: When multicasting data, each AP or relay-node transmits data only once to all clients subscribed to the multicast channel. The data transmission rate must be the minimum bit rate supported within the clients, so that they can reliably decode the content. The drawback of using the lowest supported transmission rate is that devices with a good connectivity with the AP will be penalized, and have to receive multicast data at a low rate. In addition, when AP is transmitting data at low rate, it means that it will occupy the channel radio much more time. As a consequence, the total throughput and the capacity of the AP will be limited.

We consider multicasting video stream to a set of relay-capable devices at a transmission rate r_s, supported by all relays. Relays will then forward received multicast data to other devices at a transmission rate r_c, the minimum bit rate supported within clients of each relay. We suppose that data transmitted by the AP is limited to multicast traffic. The minimum required throughput delivered by the AP to relays for a single multicasting channel is then equal to r_s. Due to the proximity between devices acting as relays and their corresponding clients, the transmission rate between relays and theirs corresponding clients, can be higher than r_c. Thus, the set of clients connecting to a relay would benefit from this proximity and gain more throughput.

TABLE III
WLAN DIMENSIONING WITH COOPERATIVE CONTENT DISTRIBUTION

Parameters	**Value**	
Seats capacity	60000	
Number of device per seat	1	
Total number of devices ψ	60000	
Take rate ρ	70%	
Number of connected devices	42000	
Duty cycle η	70%	
Percentage of device at 5-GHz δ_5	75%	
Number of concurrent devices at 5-GHz	22050	
Impaired channel throughput at 5-GHz	30Mbps	
Multicast mode (at 5-GHz)	Non-cooperative	Cooperative
Percentage of relay-capable devices	0	10%
Number of relays per AP χ_{relay}	0	20
Number of devices receiving multicast stream at 30Mbps	0	2205
Number of devices receiving multicast stream below 30Mbps	22050	19845
AP count	147	111

To measure the benefits of the multicast mode in a cooperative content distribution WLAN, we count the required number of APs and compare the achievable transmission rate at each client. To count the number of required APs in the multicast mode with cooperative content distribution, we consider the same network characteristics as in Section III-B1, i.e., ψ is the total number of devices and ρ is the take rate. The percentage of devices with the high network capabilities (capable of receiving multicast stream at 30Mbps for example) and relay-capable devices is μ. We define χ_{relay} as the number of relays per AP. Devices with the high network capabilities will be used as relays for other devices, which have lower network capabilities. The required number of APs is then calculated as follow:

$$\text{AP Count at 5-GHz} = \frac{\psi \times \rho \times \mu \times \eta \times \delta_5}{\chi_{relays}} \qquad (8)$$

As an example, if we use the same network parameters as in Section III-B1, and set χ_{relay} to 20, then the required number of APs at 5-GHz will be equal to 111. The election of relays can be based on their signal quality and their proximity with the AP. To eliminate the rate anomaly issue, the AP can be configured to only deliver high transmission rate, and thus relays will receive multicast streams with the highest possible data rates. Devices connected to relays will also benefits from their proximity to relays, and can receive a multicast stream with higher bitrate as contrary to the case where they were directly connected to an AP.

Table III shows the different benefits of using relays in HD premises, by comparing the required number of APs and the achievable per-client throughput in both unicast and multicast modes. The consequence of using cooperative content distribution in dense environments is that the number of required APs is reduced, without consuming extra bandwidth and a higher number of devices can consume multicast streams with higher data rate.

IV. CONCLUSION AND FUTURE WORKS

WLAN designers face fundamental challenges with the new demand for high levels of performance in HD environments. The WLAN structure has to offer high per-device throughput for both unicast and multicast transmission mode. We presented in this paper a guideline on how to efficiently plan a cooperative HD WLAN. We proposed to take into consideration the proximity of devices in HD environment and make them collaborate in order to lighten the network load and improve the per-device throughput. The method consisted of using users' devices, with high network capabilities, as relays for others devices with lower transmission rates. The use of cooperation between neighboring devices enhanced the network performance by notably reducing the number of APs in the case of multicasting video streams.

Several challenges still have to be investigated in order to better improve the cooperative content distribution in dense environment: (1) Relay selection: which node should be selected as relay, in order to increase network performances. A prior work on this challenge is detailed in [14] (2) Increasing overhead: how the use of relays can cause extra network overhead (3) Clustering: how to form clusters of neighboring nodes in order to improve content distribution through neighbors.

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REFERENCES

[1] A. . Kaya, D. Calin, and H. Viswanathan, "On the performance of stadium high density carrier wi-fi enabled lte small cell deployments," in *2015 IEEE Wireless Communications and Networking Conference (WCNC)*, March 2015, pp. 855–860.

[2] C. Lukaszewski, *Very High-Density 802.11ac Networks Engineering and Configuration Guide*, Aruba Networks, 2015.

[3] J. Florwick, J. Whiteaker, A. C. Amrod, and J. Woodhams, *Wireless LAN Design Guide for High Density Client Environments in Higher Education*, Cisco, 2013.

[4] *Deploying Very High Density Wi-Fi - Design and configuration guide for stadiums*, Ruckus Wireless, Inc., 2012.

[5] M. Heusse, F. Rousseau, G. Berger-Sabbatel, and A. Duda, "Performance anomaly of 802.11b," in *IEEE INFOCOM 2003*, vol. 2, 2003, pp. 836 – 843.

[6] P. Baumung, M. Zitterbart, and K. Kutzner, "Improving delivery ratios for application layer multicast in mobile ad hoc networks," *Computer Communications*, vol. 28, no. 14, pp. 1669 – 1679, 2005, applications and Services in Wireless Networks.

[7] L. Al-Kanj, Z. Dawy, and E. Yaacoub, "Energy-aware cooperative content distribution over wireless networks: Design alternatives and implementation aspects," *IEEE Communications Surveys Tutorials*, vol. 15, no. 4, pp. 1736–1760, 2013.

[8] E. Yaacoub, L. Al-Kanj, Z. Dawy, S. Sharafeddine, F. Filali, and A. Abu-Dayya, "A utility minimization approach for energy-aware cooperative content distribution with fairness constraints," *Transactions on Emerging Telecommunications Technologies*, vol. 23, no. 4, pp. 378–392, 2012.

[9] B. Zhang, Z. Zheng, X. Jia, and K. Yang, "A distributed collaborative relay protocol for multi-hop wlan accesses," in *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, Dec 2010, pp. 1–5.

[10] L. Guo, X. Ding, H. Wang, Q. Li, S. Chen, and X. Zhang, "Cooperative relay service in a wireless lan," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 2, pp. 355–368, 2007.

[11] K.-W. Chin and S. Li, "Novel association control strategies for multicasting in relay-enabled wlans," *Comput. Netw.*, vol. 56, no. 8, pp. 2168–2178, May 2012.

[12] Wi-Fi Alliance, "Wi-Fi Peer-to-Peer (P2P) Technical Specification v1.5," 2014.

[13] *Coverage or Capacity - making the best use of 802.11n*, Juniper Networks, 2011.

[14] M. A. Khan, W. Cherif, and F. Filali, "Group Owner Election in Wi-Fi Direct," in press 2016.