International Journal of Information and Electronics Engineering, Vol. 5, No. 4, July 2015

Heavy AP Backhaul Aggregation: Concepts and Impact on Wireless Networks Performance

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***Abstract*—In telecommunication networks, especially wireless, it is common for computers (machines) in residential scenarios and hotspots to see multiple access points (APs). These APs often provide wireless broadband but are connected to the Internet via independent, relatively slow links. With current wireless norms, one station is capable of connecting to only one AP. So, wireless clients must compete over throughput with all stations in the same SSID. Each client will be, therefore, left with a small portion of the bandwidth that fluctuates relatively to potential stations activity. However, in the ideal case, a client could benefit simultaneously from connections to all available access points and get the sum of their available backhaul bandwidth. Such perspective launched several proposals aiming to aggregate AP backhaul bandwidth, multiply the overall throughput and improve resources management. These propositions are basically founded on two different concepts namely the client based and the AP based backhaul aggregation.**

***Index Terms*—Aggregating AP, backhaul bandwidth, co-channel signaling, fair backhaul aggregation, sharing AP.**

I. Introduction

Given the growing discordance between the speed of residential broadband and the current IEEE 802.11 standards, the backhaul aggregation has been introduced as an innovative technique, where residential customers could benefit from much higher speed. Generally, the backhaul aggregation's purpose is to integrate the ability of simultaneous connections to several reachable access points. The idea consists, basically, of using the available (spared) backhaul bandwidth at a given AP to supply either its own customers or its neighboring peers (see Fig. 1).

In other terms, AP backhaul capacity aggregation opens up perspectives to:

- Enhance the speed of AP-Clients connections
- Capitalize the spared APs' backhaul bandwidths to improve throughput partition among wireless nodes
- Split connections overload equitably between approximate neighboring APs (see Fig. 2)

In this paper, we are going to mention, at first, some of suggested aggregation approaches. We are going to detail, then, our theory concerning an enhanced backhaul aggregation solution.

Manuscript received August 10, 2014; revised November 20, 2014.

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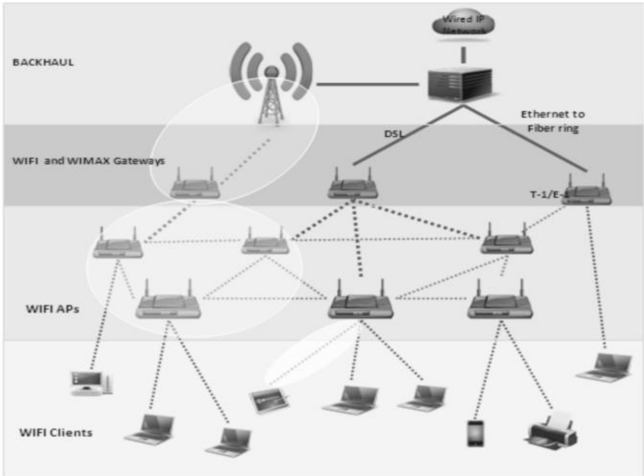

Fig. 1. Wireless network architecture.

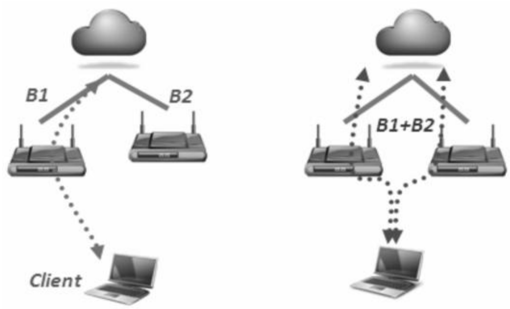

Fig. 2. AP backhaul aggregation.

II. Related Work

Several prior studies envisaged AP backhaul aggregation as a solution for higher network efficiency and larger throughput for both access point and wireless clients. From this stand point, we distinguish a distributed architecture and a centralized architecture respectively implemented in «Client based» and «AP-based» aggregation schemes. In this section, we are going to report some of those approaches in terms of consistency with our ulterior solution.

Actually, client-based solution is a distributed approach that defines hardware and-or software improvements at the station level precisely the MAC layer (Media Access Control). Such improvements are designed to enable wireless clients to connect simultaneously to multiple APs.

These ameliorations could involve:

- Drivers or protocols intended to perform switching tasks between AP accordingly to link status and AP availability (e.g.: FatVAP [1], WiSwicher [2], and THEMIS [3]…)
- Virtualization mechanisms splitting the wireless card into multiple virtual cards connecting respectively to

DOI: 10.7763/IJIEE.2015.V5.537

different APs (e.g.: Multinet [4], Juggler [5], and VirtualWifi [6]…).

As efficient as the client mode solution may seem, it is yet, subject to various gaps. As the client side is concerned, each potential changes must be applied to each involved one, including naturally, cost challenging deployment. So, in order to offer the possibility of using the backhaul capacity to any type of wireless equipment, the solution should suggest changes for unexpected upcoming clients.

Furthermore, several client-based backhaul aggregation schemes greedily maximize individual station's throughput regardless to fairness issue. Such scenario leads to roughly unfair throughput distributions, discourage user participation, and severely limit commercial feasibility.

As for the AP-based solutions, such as SmartAP [7], Sidekick [8], the logic is inverted. Instead of upgrading the client features, those proposals focus on the AP side. In fact, their purpose is to concentrate hardware-software improvements into centralized equipments (APs). Even though, related access points have much more tasks to execute, they are definitely more efficient than ordinary stations.

Even though, in such case, client «fate» is defined by access points' performance, the AP-based objective is mostly, to make the backhaul bandwidth aggregation practically feasible and easier to implement. To do so, those proposals vise access points improvements and manages to satisfy the following requirements:

- A marketable solution involving limited changes to a minimum number of equipments
- A single radio channel solution: an acceptable cost solution with no need of additional hardware
- Unmodified wireless customers: a solution that enables any type of wireless equipment to use available backhaul bandwidths
- Priority administration: a given AP must primarily dedicate its backhaul connections to serve its owners (primary users). An AP is allowed to give up, only the free part of the backhaul capacity for its neighboring APs (See Fig. 3)

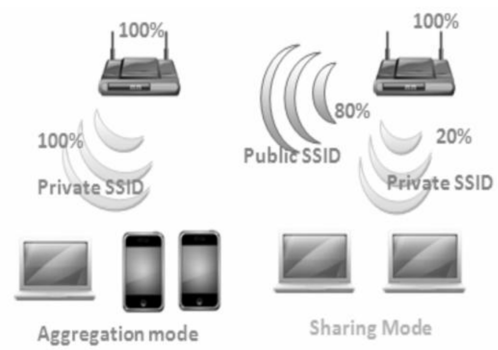

Fig. 3. Bandwidth distribution schemes.

Therefore, we are going to suggest, in this paper, an AP-based solution. We will try to display a sophisticated approach that combines various technologies and implement several concepts in the same architecture. In our proposal, we intend to enhance aggregation scheme by merging client-based strengths to AP-based effectiveness**.**

III. HeavyAP Solution

In this section, we are going to exhibit our approach of an AP-based aggregation scheme, we called HeavyAP. We implicated former solutions and gathered up the advantages of some approaches into one proposition. We integrated innovative features in order to optimize backhaul bandwidth utilization and overall throughput distribution.

A. General Description

HeavyAP is an AP-based solution including major changes at APs' level. These changes aim to reduce signaling overload, maximize APs performance and ensure fair traffic management for both AP and client sides.

Indeed, HeavyAP principally covers the following features:

- Adaptive AP's operational mode
- Dynamic AP's status table
- Interfering co-channel signaling
- Fair backhaul aggregation algorithm

Each cited feature will be detailed, separately, in the following paragraphs.

B. Adaptive Operational Mode

HeavyAP architecture implements the possibility to share the backhaul capacity, not only, with wireless clients, but also, with approximate APs. However HeavyAP owners are privileged (primary costumers) over neighboring AP (regular costumers). As long as primary clients are in need of bandwidth, no other client has access to such resource. In fact, HeavyAP distinguishes two possible operation mode based on access point backhaul bandwidth status (in excess or in default).

1) Sharing or shared mode (SM)

In this mode the access point offers the spared bandwidth (primary customers do not need), to neighboring APs craving for additional throughput. So HeavyAPs broadcast their status as «willing to share» for the neighboring APs in aggregation mode (AM). These latter may then, choose between available sharing APs according to their needs. Exceeding backhaul capacity is shared through a public SSID while the sharing AP's owners (primary costumers) connect through a private SSID.

In fact, as the wired backhaul capacity is not virtualized, private SSID takes precedence over the public SSID and the private flow is differentiated from the shared one.

2) Aggregating or aggregation mode (AM)

In this mode current AP lacks of free bandwidth to share and fails to satisfy its clients' entire need. It initiates consequently, a search for neighboring AP willing to cede some of their available backhaul capacity. Indeed, in this mode the owners of the access point consume the entire backhaul capacity.

Currently unable to share his backhaul capacity, aggregating AP does not diffuse a public SSID. To improve the offered rate to its customers and acquire additional throughput, it scans the radio channel to check the status of other APs (whether a public SSID is broadcast).

However, HeavyAP in AM mode has to establish a balance between its role as Access Point (serving its wireless clients-stations) and its commitment to retrieve more bandwidth. In fact, aggregating AP should adequately divide its wireless period between its own transmission frequency (send transmitted data to their destinations) and sharing APs' radio frequencies (to assemble the required backhaul bandwidth from available APs) See Fig. 4.

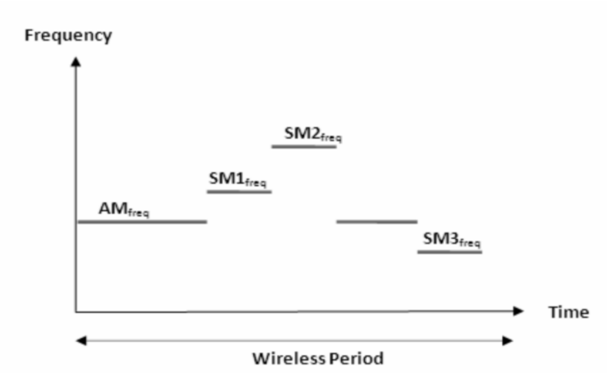

Fig. 4. Wireless period distribution.

where:

- SM: accessible Sharing Mode AP
- AM: current Aggregating AP

C. *Dynamic AP's Status Table*

Since each AP has two possible operating modes (AM and SM), switching between modes must take into consideration the clients «waiting for data» and APs «holding for spared backhaul capacity». AP status are, therefore, saved into a status table that includes all required information about current AP and neighboring sharing mode APs. Any aggregating customer should consult status tables of reachable AP before getting involved into any transaction.

However, only sharing AP could diffuse their status table contents (public SSID), as long as they are concerned by the aggregation procedure contrarily to aggregating APs (which only use their private SSID). This status table could be described as follow (see Table I)

TABLE I: AP STATUS TABLE

Current AP	SSID	Available Bandwidth	Neighboring SM APs
SM	Public SSID	B	SSID1
			SSID2
			SSID3

AP status table should be limited in size to minimize the scanning time. So, only better rated sharing AP are included. Furthermore, status features should be diffused over overlapping co-channels in order to reduce signaling overload between APs and avoid meaningless connections.

D. *Interfering Co-Channel Signaling*

In previous solutions, radio customers overcame the problem of backhaul aggregation. Indeed, wireless clients connect to multiple access points one at a time: order and connection time is limited by different parameters such as bandwidth, queue size, congestion of the link. And this is applicable for radio and backhaul link channel. However, two major obstacles impede effective connectivity plans between multiple APs and single radio clients.

First, client nodes could communicate with only one AP at a time which creates a «chicken-egg» conflict: in one hand, the customer should know the available bandwidth of an AP, before building a connection schedule. In the other hand, he could not know the backhaul available capacity before establishing connection to the AP, measuring or downloading traffic statistics.

In this context, we suggested to implement a new 802.11a/g/n aggregation scheme protocol. It could achieve an effective multi-AP connection schedule. Such concept is based on co-channel signaling protocol. It assigns to APs an active role in the aggregation procedure by notifying customers of parameters and link state through an in-band signaling channel avoiding thereby, the signaling traffic and links overload.

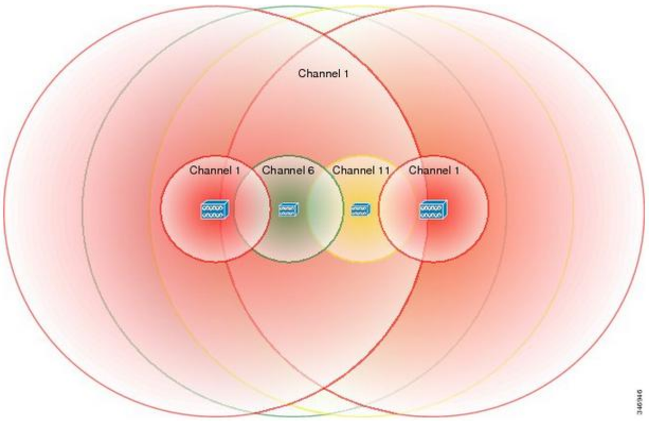

Fig. 5. AP with 20 percent overlap and co-channel interference boundaries [9].

The key innovation in this approach is the fact that the client (aggregating AP) no longer needs to be on the same channel of the sharing AP to acquire status information. In fact, the technique of in-band signaling can transmit efficiently and accurately bandwidth information for customers granted on channels partially overlapping with the serving AP channel (see Fig. 5).

This approach envisages a MAC layer protocol that integrates real-time traffic information with optimal schedule to maximize achievable throughputs over several APs. It offers certain advantages over existing aggregation techniques:

- Retrieve traffic information through partially interfering channels: Corresponding nodes can exchange information of link state as the spectrum of the channel used by the AP partially overlaps the spectrum used by the customer. Both client and AP do not need to be connected to the same radio channel. Unlike older protocols, this solution uses a new channel for reliable signaling, operating with standards based on OFDM (802.11a/g/n) and an independent performance bandwidth of the spectrum interference.
- Low signaling overhead: The HeavyAP nodes could exchange the required information flow with minimal overhead. Customers located in interfering channels can acquire information files from parallel channels without necessary use of bit signaling or additional

synchronization. This is in contrast to regular co-channel communication that requires their own signaling procedure in the form of predefined preamble with media access protocols.

- Elaborated administration of media state: As a result of the co-channel signaling, the customer could effectively conclude the sharing APs to target and the amount of available bandwidth over the time, with a minimum of probing overhead (see Fig. 6).

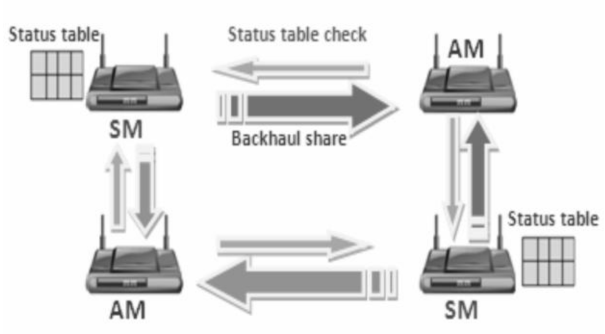

Fig. 6. AM-SM access points exchange.

Thus, each AP should include in his table the most rated APs in sharing mode and periodically update the corresponding values (each wireless period). These APs are selected according to their contribution (available wireless and backhaul capacity). In such way, we eventually reduce vainly inter AP switching by shunting the aggregating AP toward the better sharing ones.

As multiple APs could be concerned by the backhaul aggregation, a competitive situation may arise. In fact each aggregation AP tries to benefit greedily from accessible sharing ones to satisfy the most its wireless clients. It is, then, compulsory to establish order between "players" and fairly allocate spared backhaul bandwidth.

A. Fair Backhaul Aggregation Algorithm

1) Description

In HeavyAP solution we propose to develop a fair partition of spared bandwidth between all aggregating APs.

Whereas, the idea of fairness should covers the following aspects:

- Across- aggregating AP fairness: ensures fairness at the level of the aggregating APs' totally received throughput proportionally to their requirements.
- Weighted fairness: ensures fairness relatively to subscription plans or priority level. Indeed, APs with better subscription plans (e.g. faster broadband links) obtain greater share of the aggregated backhaul bandwidth than APs with cheaper subscription plans.
- Load balance fairness: ensures fairness across all sharing APs, in terms of load overflow.
- Efficient fairness: provides an efficient fairness scheme, in terms of network utilization, and creates balance between fairness and throughput.
- Stable fairness: provides a stable fairness scheme with good convergence properties.

To do so, we mapped a client based solution approach (namely THEMIS) to our AP-based solution. With the difference that our clients are actually access points rather than wireless stations. Our formulation, essentially, aims to guarantee fairness between all network's APs, when comes to sharing backhaul capacity. The wireless stations are, as a consequence, concerned by the throughput's gain.

2) Algorithm

In order to represent this approach we consider:

- A_m the number of aggregation mode APs
- S_m the number of available sharing mode APs.

Our solution aims to maximize the total wireless capacity of the sharing mode APs (considered in this case as clients). That is, within the limit of the radio resources:

$$\max \sum_{k \in A_m} U(y_k) \quad (1)$$

Maximize Utility at aggregating APs level:

$$y_k = \sum_{i \in S_m} T_{ik} \quad (2)$$

where $\boldsymbol{y_k}$ is the sum of the throughput received by the client $\boldsymbol{k}$ ($\boldsymbol{A_{mk}}$: an aggregating AP) from all the sharing APs ($\boldsymbol{S_m}$).

This relation is limited by the backhaul capacity constraint in (3). In fact, the sum of the throughput received by all aggregating APs from one sharing AP $\boldsymbol{S_{mi}}$ could not exceed the available backhaul capacity $\boldsymbol{b_i}$ of this latter

$$\sum_{k \in A_m} T_{ik} \le b_i, \forall i \in S_m \quad (3)$$

where $\boldsymbol{T_{ik}}$ is the throughput delivered by the $\boldsymbol{S_{mi}}$ toward $\boldsymbol{A_{mk}}$. Whereas, the bandwidth capacity delivered from one sharing AP and aggregating APs could not exceed the wireless capacity of the sharing one $\boldsymbol{w}$ (see Fig. 7).

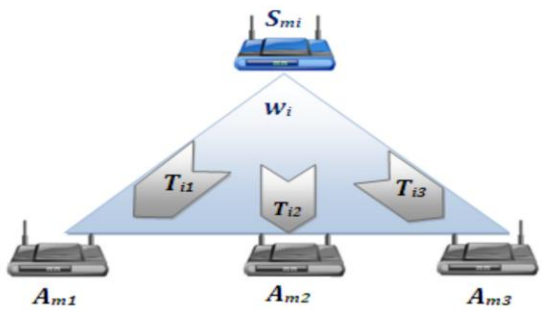

Fig. 7. Wireless capacity constraint.

Then,

$$\sum_{k \in A_m} \frac{T_{ik}}{w_i} \le 1, \qquad w_i > 0, \forall i \in S_m \quad (4)$$

This constraint ensures that the maximum capacity of the wireless interface of the sharing access point $\boldsymbol{S_{mi}}$ is not exceeded.

However analytically, this constraint could be violated in the extreme cases of aggregating clients severely limited by the wireless capacity. We could avoid this situation by preventing client from connecting to sharing AP with really low SNR rate. In this sense, the aggregation multi-AP scheme is only useful when the wireless capacity is superior to the backhaul capacity of the AP (sharing AP).

From aggregating AP, $\mathbf{A_{mk}}$ point of view, the overall throughput could not exceed its wireless capacity, i.e.:

$$\sum_{i \in S_m} \frac{T_{ik}}{w_k} \le 1, \qquad w_k > 0, \forall k \in A_m \tag{5}$$

Ultimately, we could choose a utility function proportional to priority level:

$$U(y_k) = p_k \log(y_k) \tag{6}$$

where $\boldsymbol{p_k}$, is the priority level of the aggregating AP: $\boldsymbol{A_{mk}}$. So, if all aggregating APs have the same priority then $\boldsymbol{p_k}$ =1

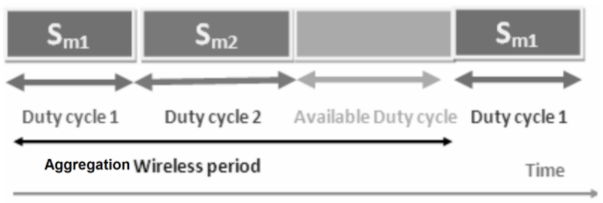

Fig. 8. TDMA cycle for an aggregating AP.

Consequently, the targeted AP chooses his better rated bandwidth suppliers, initiates connections and sum up the ensemble of the collected capacity (see Fig. 8).

Within such demarche, we could eventually satisfy aggregating APs' requirement while ensuring respectable level of fairness and network efficiency.

IV. Conclusion

In this paper, we focused on AP backhaul aggregation scheme in WLAN (Wireless Local Area Network).Indeed we differentiated client-based and AP-based solutions. Since, client-based approaches need ultimate client adjustments, their deployment has been cost prohibitive and technically challenging. We propose consequently a solution that takes the next step by aggregating bandwidth across many available APs, eventually scattered across different channels. Apart from virtualization theories like in [10], our solution HeavyAP is, actually, a compromise between client-based and AP-based approaches. This new approach requires only software improvements at the APs level, controlled by the network operator. In order to achieve optimal network performance, we envisaged several enhancements, inter alia, an interfering co-channel signaling, adaptive operation mode, dynamic status table and fairly distribution algorithm.

As a consequence a complete re-design of the system is requiring novel protocols and software adjustments to enhance the achievable aggregated throughput over multiple APs.

As a next step, we intend to experimentally implement our solution and generate, with real wireless architecture, the network response. And, with provided statistics we demonstrate our contribution in terms of throughput distribution, efficiency and balanced resource management.

Acknowledgment

I would like to express my very great appreciation to my supervisor Mr. Mounir FRIKHA for his continuous support and encouragement. I am particularly grateful for the upholding given by my husband and my parents. I am especially thankful to my little girl who showed much patient and love. My special thanks are extended to the staff of Higher School of Communications, Sup'Com, for their cooperation and consideration.

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