A Proposal for Elastic Spectrum Management in Wireless Local Area Networks

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***Abstract*—The last hop of the Internet towards the end-user is mostly supported by wireless technologies and thus interconnects multiple users, that should, ideally, be served simultaneously. The shared media capability of such last hop is, however, underused, asthe principle behind wireless technologies implies that only one user can be served at an instant in time. Aiming at allowing multi-user transmission within a specific time-frame, this technological demonstration goes over a novel wireless extension mechanism explaining how it can be applied to current wireless networks while keeping backward compatibility.**

I. Introduction

User-centric networks (UCNs) reflect a recent architectural trend of self-organizing, autonomic networks where the Internet end-user cooperates by sharing network services and resources. UCNs are characterized by spontaneous and grassroots deployments of wireless architectures (e.g. ad-hoc or infrastructure), where users on such environments roam frequently and are also owners of networking equipment (e.g. residential *Access Points*, *APs*) thus playing an active role in terms of topology changes (e.g. APs that dynamically become active or inactive). Thus, the technology that is usually considered in these environments is *Wireless Fidelity (Wi-Fi),* namely, IEEE 802.11 standards.

In IEEE 802.11, when one device (a station) triggers communication, it prevents the others of communicating during a specific time-frame – contention is the process applied to deal with collisions derived from the communication across the shared media. Such design results in an unfair MAC Layer, which is not appealing to scenarios such as UCNs.

The issue concerning such unfair nature has been addressed in the context of the European project *User-centric Wireless Local Loop (ULOOP) [1],* being the intention to devise a software based solution that could be applied to existing infrastructures to provide more fairness while allowing to serve multiple users within the same time slot. This solution, *Elastic Spectrum Management (ESM)* [4], operates on the MAC Layer and hence its operation has no implication whatsoever to any of the other OSI Layers. Furthermore, ESM can be applied in current infrastructures without requiring any changes in hardware.

For IEEE 802.11 standards that rely on OFDM, our solution introduces several benefits. Firstly, latency can be reduced. By allowing data to be transmitted to multiple stations in the same timeframe, our solution provides a way to circumvent the original design of the MAC Layer which requires contention (1 station at a time) to be served. Secondly, the reduction in latency and the possibility to prioritize requests according to specific fairness rules e.g. station priority, introduces a way to prevent problems such as the "hidden station" problem. For instance, today if one slow station grabs the medium first to transmit e.g. 100 Kbytes of information, the other stations have to wait until they can transmit, no matter how prioritary the communication may be. While with our solution, stations are first identified based on a specific set of priorities, and then multiple stations are served based on that same priority. Thirdly, we state backward compatibility in our solution, namely, the solution to be demonstrated has been designed to ensure that the new system could be fully compatible with existing systems, thus ensuring that by introducing improvements, the operation of the network is feasible and does not increase in terms of complexity.

II. Elastic Spectrum Management

The ESM software architecture has been implemented as a patch to the UNIX module mac80211, and has two modes of operation, *node* or *gateway*. Usually, the node mode is activated if ESM is installed in a Wi-Fi station, while the gateway mode is activated if ESM is installed in a Wi-Fi AP.

When operating in gateway mode, ESM controls the amount of OFDM sub-frequencies that a gateway can assign to multiple users downstream (from the controller to the station), as well as the way that the MAC layer controls the access to the configured sub-frequency chunks. The number of sub-frequencies that a gateway can assign to a node depends on the node relevancy within a specific context, which in ULOOP is related to a trust level[1] within a specific community [2].

When operating in node mode, ESM simply interprets the information that is sent by a gateway to multiple users. Both modes are detailed in the next sub-sections.

ESM is therefore a mechanism that changes only the way that Wi-Fi transmits downstream. During upstream communication (from a station to a controller), ESM follows the

[1]ESM has been implemented in an independent way and therefore, other parameters, instead of the trust notion, can be used to define a notion of fairness.

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regular MAC operation, as defined by IEEE 802.11 standards and hence, stations must still deal with MAC contention, if available. The validation of this mechanism as well as the performance improvements are out of the scope of this demonstration, as they relate with our prior work [3][2].

A. Gateway Mode

Each time a station s_i requests resources from a controller (in Wi-Fi, an AP), the controller maps s_i to a virtual queue, which is established via usual MAC virtualization techniques. Such assignment provides a way to serve stations based on specific priorities – the highest priority stations get served first and may get greater amount of resources than other stations. For instance, in ULOOP, such priority relates with the trust level that the gateway has on a specific station, which by itself is a product of several aspects, such as recommendations sent by other networking devices. Other forms of priorities can be considered to develop an adequate scheduling mechanism, that satisfies both the network and the user expectations.

The controller periodically checks the queues assigned to each station, and extracts information to create an aggregated MAC payload. Such payload holds sets of bits for several stations s1, ..., sn. This is not a new MAC frame; instead, we simply consider a new way to interpret the MAC frame payload. Hence, stations that implement ESM interpret the modified payload, by extracting only the bits that are assigned to them; regular IEEE 802.11 stations will simply discard that content, following the regular MAC Layer procedure.

To be capable of providing such a payload, ESM relies on a specific bit-arrangement technique, which considers that for each OFDM symbol transmission, data bits from s1 to sn can be transmitted simultaneously. In IEEE 802.11g, the number of inputs to IFFT is $N = 48$, where $N$is then split across the number of stations to serve in a duty cycle. For instance, if we consider two stations, e.g. s_1 and s_2, the controller applies its specific priority policy which for our example would result in allocating 12 inputs to s_1 and 36 inputs to s_2. The used technique also considers the modulation level, i.e. M bits per input, supported by the current transmission period. In total, the IFFT has $N * M$ bits capacity per OFDM symbol. In our example, assuming a modulation level $M = 4$ in each OFDM symbol transmission a series of $48 * 4 = 192$ bits would be transmitted, where the first $12 * 4 = 48$ bits are directed to s_1, and the remainder $36 * 4 = 144$ bits are intended to be sent to station s_2.

B. Node Mode

When operating as node mode, the station checks each frame received and looks for a specific flag at the MAC header, which identifies a MAC frame as an ESM frame. If this is a normal station (not implementing ESM) the regular MAC procedure for unknown frames is applied. If it is an ESM frame, the station extracts from the payload the blocks of bits that are identified via its own identifier. This is a specific identifier that ESM considers, and which is provided by the controller to the stations, when accepting a request to connect. Data identified as belonging to other stations is discarded via the regular MAC operation. A specific data length parameter (provided as control bit) allows a station to ensure that it gets its own data block. Moreover, the last block is identified via an *End of Data (EoD)* flag. The station then puts all of the received pieces of data in a new MAC frame which is solely used to allow the MAC operation to proceed without changes.

[2]ESM is available as open-source software licensed under LGPLv3.0, via the URL Available at http://uloop.eu/software/RM.zip.

III. Demo Scenario

The demo, represented in Figure 1, consists of two APs and two stations connected to the AP via a specific SSID, ULOOP_OPEN. The APs rely on the Atheros chipset AR7240, and both APs run OpenWRT Backfire 10.03.1. The AP identified as ULOOP has in addition ESM installed. Station A is a Toshiba Satellite L850-1P9, running Ubuntu 12.04 with kernel 3.5. Station B is a Toshiba Satellite Pro R850-1JJ, running Ubuntu 11.10 with kernel 3.0. The demo shows the performance of ESM against IEEE 802.11g, based on real streaming of videos, via the Internet.

Figure 1. Demo scenario.

The data rate is limited to 1Mbps to emulate the MAC broadcast operation, as ESM is a control plane mechanism.

What this demo shows is that ESM reduces inter-packet delay, due to the downstream multi-user transmission. By reducing delays, ESM provides a better user experience and improves network fairness.

IV. Summary

This technological demonstration goes over ESM, a software defined extension of Wi-Fi that allows for downstream multi-user transmission and that is backward compatible with IEEE 802.11 standards.

V. Acknowledgements

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