A Utility Maximization Approach to MAC Layer Channel Access and Forwarding

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Abstract— This work takes a nonlinear utility optimization based approach to allocate bandwidth channel resources among interfering interfaces both in presence of balanced and unbalanced traffic. A new algorithm is proposed to leverage channel related access information in dynamic network scenario for optimal performance. Preliminary results from implementation of nonlinear utility maximization based on data rate and tested indoor IEEE WLAN 802.11n+s on ns-3 simulation are presented. Implication of economic perspective of resource allocation and technological efficiency of WLAN is demonstrated. Experimental software developed under this work, naturally leads to a programmable interface for management and control of physical layer resources in an optimal fashion.

1. INTRODUCTION

With the advent of multiple interfaces unbalanced traffic in network is created in a systematic fashion. Generally speaking, in unbalanced traffic there is a requirement for an efficient scheduling mechanism that should restrict the data rates of all the interfaces to the maximum achievable data rate for the corresponding end-to-end flow. This reduces the packet overflows at the intermediate mesh station (MS), as well as maximizes the network capacity and the spatial reuse. First, a subflow should not transmit in a data rate which is more than the maximum achievable data rate for the corresponding flow, and second, channel bandwidth should be proportional to its traffic load so that sub-flows can pass through it.

This work proposes a joint channel access and forwarding protocol, which extend the standard EDCA and HWMP in IEEE 802.11s, to solve the unbalanced traffic allocation problem among the end-to-end flows. Major points of discussion are:

1) The balanced and unbalanced traffic aware resource allocation among the contention in a multi-interface directional Wireless Mesh Network (WMN) as a convex optimization problem.
2) The link metric used for path establishment in HWMP is augmented based on the channel access information, to support the optimality of the solution obtained for the balanced traffic allocation, in a dynamic spectrum scenario where new traffic flows are introduced, or existing traffic flows are terminated randomly, and.
3) The augmented EDCA and HWMP protocols are implemented in a practical indoor IEEE 802.11n+s multi-interface mesh test bed at ns-3 to evaluate the performance in real-life scenarios.

The rest of this paper is organized as follows. Section 2 describes the related work. Section 3 presents the proposed solution for balanced and unbalanced traffic and implements a preliminary version of nonlinear utility maximization based on data rate. Section 4, describe basic ns-3 test bed for indoor IEEE WLAN 802.11n+s. Section 5 reports performance evaluation results and Section 6 concludes with future directions.

2. RELATED WORK

TDMA and probabilistic scheduling as access protocol techniques are used in multi-directional antenna for efficient and unbalanced traffic. An exponential linear programming formulation for joint routing and scheduling in multi-hop wireless networks with directional antenna [1] is based on TDMA/FDMA scheduling and centralized in nature and improves the performance. In [2], authors propose a mixed integer linear programming solution to minimize interference among different interfaces in multi-interface directional antenna based wireless networks. In [3] a linear programming formulation for maximizing network throughput subject to fairness constraint and directional antenna based channel interference constraint has been provided. Based on the optimization formulation, they propose a heuristic for joint link scheduling and routing scheme which aims at approximately optimal solution. Nonlinearity have been included in the routing and spectral assignment algorithms by including a nonlinear constraint [4] and through a power optimized reach constraint [5]. In particular, results presented in [6] are advantageous where correct routing and spectral assignment can lead to improved SNR and throughput. A nonlinear weight has been introduced by design in the optimization objective function to initially group highly interfering channels so that they can be subsequently given well separated spectral assignments. Finally individual transmission powers were optimized to maximize the reach [7] while in [8] an altruistic minimization of transmitted power was found to benefit the wider network. Here, we take a global view of the network and adjust individual transmitter powers to equally distribute the available SNR margin above error free transmission.

3. RELATED WORK

Network model describes IEEE 802.11s EDCA and HWMP protocols, the interference characteristics for a multi-interface directional mesh network. IEEE 802.11s standard defines EDCA as the mandatory and MCCA optional MAC layer channel access protocol. The standard provides HWMP as the forwarding protocol. The existing IEEE 802.11 distributed coordination function (DCF) is extended through Enhanced Distributed Channel Access (EDCA), which incorporates a number of mechanisms to provide differentiated QoS service by giving different access priorities to different access categories (AC). Hybrid Wireless Mesh Protocol (HWMP) IEEE 802.11s uses HWMP for MAC layer data forwarding. As a hybrid protocol, HWMP aims at merging advantages of both proactive and reactive routing mechanisms. It can be configured to operate in two modes — on demand reactive mode and tree-based proactive mode.

Architectural & Usage Models in 802.11s

- Mesh Portal: Interface between external Internet and others node, works as gateway.
- Mesh STA: Works as Relay frames in a router-like hop-by-hop fashion.
- Mesh AP: provide services to clients and work as Mesh relaying function as given in Figure 2.

This example indicates that the load should be weighted according to the number of hops to the destination. We call this new metric the *weighted-load* metric.

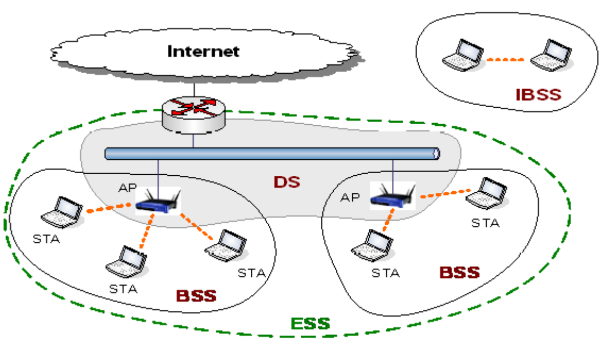

Figure 1. Network model.

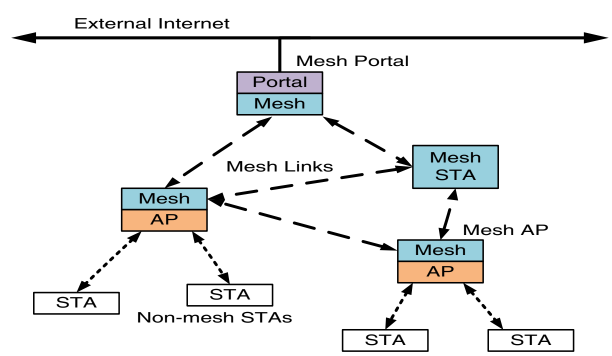

Figure 2. Network model 802.11s.

3.1. Proposed Utility Maximization Approach and Channel Assignment Protocol

BGP controlled Traffic with Unequal Bandwidth Allocated to the Paths: The multipath option removes the tiebreakers from the active route decision process, thereby allowing otherwise equal cost BGP routes learned from multiple sources to be installed into the forwarding table. However, when the available paths are not equal cost, you may wish to load balance the traffic asymmetrically. Once multiple next hops are installed in the forwarding table, a specific forwarding next hop is selected by the load-balancing algorithm. This process hashes against a packet's source and destination addresses to deterministically map the prefix pairing onto one of the available next hops. Per-prefix mapping works best when the hash function is presented with a large number of prefixes, such as might occur on an Internet peering exchange, and it serves to prevent packet reordering among pairs of communicating nodes.

An enterprise network normally wants to alter the default behavior to evoke a *per-packet* load-balancing algorithm. Per-packet is emphasized here because its use is a misnomer that stems from the historic behavior of the original Internet Processor ASIC. In reality, Networks routers support per-prefix (default) and per-flow load balancing. The latter involves hashing against various Layer 3 and Layer 4 headers, including portions of the source address, destination address, transport protocol, incoming interface, and application ports. The effect is that now individual flows are hashed to a specific next hop, resulting in a more even distribution across available next hops, especially when routing between fewer source and destination pairs. With per-packet load balancing, packets comprising a communication stream between two endpoints might be re-sequenced, but packets within individual flows maintain correct sequencing. Whether you opt for per-prefix or per-packet load balancing, asymmetry of access links can present a technical challenge. Either way, the prefixes or flows that are mapped to, for example, a T1 link will exhibit degraded performance when compared to those flows that map to, for example, a Fast Ethernet access link. Worse yet, with heavy traffic loads, any attempt at equal load balancing is likely to result in total saturation of the T1 link and session disruption stemming from packet loss. Networking community encodes the bandwidth of a given next hop, and when combined with multipath, the load-balancing algorithm distributes flows across the set of next hops proportional to their relative bandwidths. Put another way, if you have a 10-Mbps and a 1-Mbps next hop, on average nine flows will map to the high-speed next hop for every one that uses the low speed. Use of BGP bandwidth community is supported only with per-packet load balancing. The configuration task has two parts:

- Configure the external BGP (EBGP) peering sessions, enable multipath, and define an import policy to tag routes with a bandwidth community that reflects link speed.
- Enable per-packet (really per-flow) load balancing for optimal distribution of traffic.

3.2. Utility Maximization Approach: Data Forwarding Based on Interface Scheduling

As per HWMP routing policy, ALM is calculated based on frame error rate and corresponding physical transmission rate. This suffers suboptimal routing due to following reasons — 1st, the observed frame error rate changes with new flow due to the changes in interference characteristics, and 2nd is physical transmission rate does not reflect the actual data rate that a newly admitted sub-flow in a link can achieve based on balanced traffic allocation. As a consequence, a newly admitted sub-flow may choose a link that result in low end-to-end data rate as well as high interference. The utility maximization approach based on balanced and unbalanced traffic allocation returns the actual data rate that a flow can achieve. Therefore, Utility maximization approach extends the HWMP routing policy based on the actual achievable data rate of a flow. A change in routing decision results in a new communication graph. However, in a mesh network, scheduling and routing decisions are recomputed after a timeout interval. The scheduling decision adjusted at every DTIM interval, while routing decision is reexamined after every routing timeout interval. The routing paths do not change significantly unless there is an event generation or change in the network graph or in the end-to-end flow parameters. The scheduling decision can safely use the communication graph based on the previous routing decision, and once the routing paths change (implies corresponding change in the communication graph) due to the change in network graph. The proposed augmentation in HWMP based on scheduling information, termed as maximum utilization approach-HWMP, works as follows. After the routing timeout at a source mesh STA for an end-to-end flow (it can be noted that an end-to-end flow is determined by a pair of source mesh STA and destination mesh STA), the mesh STA needs to re-compute the path to the destination mesh STA. For this purpose, it broadcast a PREQ message through all its interfaces that contains the routing metric and the destination mesh STA. In the proposed, the PREQ message also contains a third parameter, termed as 'Effective Data Rate' (EDR), that denotes the actual data rate that a flow can achieve, based on the scheduling policy, when it traverse through a link. Rather than using a fixed transmission rate, EDR is used to compute the augmented ALM, termed as 'Scheduling based ALM' (S-ALM). The calculation of EDR is based on a special characteristic of a link, called "maximally loaded". Two types of flows are randomly distributed in the network — flows from the mesh STAs to the mesh gateway, and intercommunication among the mesh STAs. Proposed protocol is implemented as loadable kernel modules (LKM) in the IEEE 802.11s protocol stack. This LKM is triggered when a mesh STA is in operation (either transmit or receive) to find out the balanced traffic allocation and tune the EDCA parameters for effective channel access. The HWMP protocol is also augmented with the proposed S-HWMP. The mesh STAs are configured to operate in 300 Mbps data rate with MIMO dual streaming, along with the standard mesh channel access and peer selection protocols. The gateway is connected with the Internet through a Gigabit Ethernet LAN, and we assure that the wired network has sufficient bandwidth available so that it does not affect the mesh performance. The settings for IEEE 802.11s parameters are given below in Table 1.

Table 1.

Proactive Route Timeout	3000 TUs
Reactive Route Timeout	200 TUs
DTIM Interval	60 TUs
Beacon Interval	2 TUs
HWMP Maximum PREQ Retry	3
Mesh TTL	16
Mesh Holding Timeout	500 ms

Table 2. Simulation results.

Node No	interface	Tx packets	Tx Bytes	Tx Pkt/1s	Tx bit/1s	Rx packets	Rx Bytes	Rx Pkt/1s	Rx bit/1s	Time Second
0	1	109	12468	0	0	107	11540	0	0	26.198
0	2	158	165432	10.3359173	87648.57881	1	28	0	0	26.198
1	1	156	163312	10.3359173	87648.57881	1	28	0	0	26.198
1	2	158	165432	10.3359173	87648.57881	1	28	0	0	26.198
2	1	111	114588	0	0	1	28	0	0	26.198
2	2	109	112468	0	0	1	28	0	0	26.198
3	1	159	165468	10.3359173	87648.57881	157	164140	10.33592	876480.58	26.198
3	2	110	112504	0	0	0	0	0	0	26.198
0	1	222	232248	10.3359173	87648.57881	221	223468	10.33592	869870.08	54.008
0	2	316	332912	0	0	1	28	0	0	54.008
1	1	273	287332	10.3359173	87648.57881	1	28	0	0	54.008
1	2	376	396512	10.3359173	87648.57881	1	28	0	0	54.008
2	1	214	223768	0	0	1	28	0	0	54.008
2	2	213	222708	0	0	1	28	0	0	54.008
3	1	264	276768	0	0	263	275652	0	0	54.008
3	2	276	288464	10.3359173	87648.57881	0	0	0	0	54.008

4. PERFORMANCE EVALUATION

We have performed simulations using the ns-3 simulator to evaluate the performance of the proposed protocol. A simulation area of $1000 * 1000\,\mathrm{m}^2$ is divided into 4 quadrants, and APs are placed at the center of each quadrant. All AP are assigned different channels. 1 nodes were randomly placed in each quadrant, making a total of 4 nodes. To create an unbalanced traffic pattern, the 1 node in the northeast quadrant was selected as destinations that receive traffic from the AP. Then we simulated balanced traffic that each quadrant selected as destinations. Under this scenario, we have compared two protocols. The first one which we call "MCP" assigns channels randomly and selects routes based on number of hops, without any consideration of traffic load is running on interface 2. The second one is the proposed protocol UMA (utility maximization approach) which is running on interface 1.

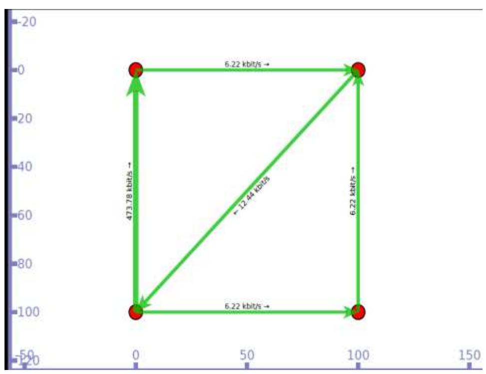

Figure 3. Simulation.

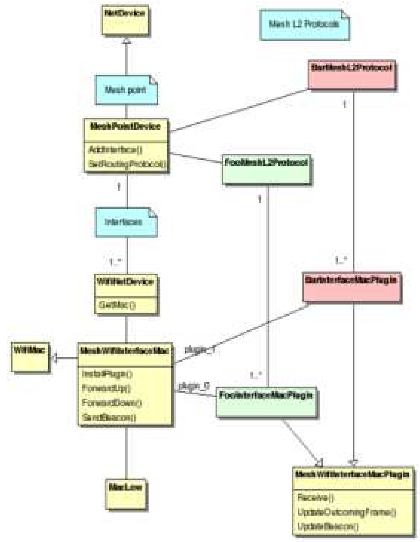

Figure 4. Simulation flow chart in NS3.

5. CONCLUSION OF WORK

In this proposed work each mesh node has multiple interfaces used to get maximum data rate in distributed environment. Based on data rate and data traffic at channels we selected mesh access point which connect to external network. Finally based on balanced and unbalanced traffic demand we selected interfaces of every mesh node to improve the performance of IEEE 802.11s EDCA and HWMP supported wireless mesh networks.

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