Is there a Need for Multiple APs in Home Networks?

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ABSTRACT

Wireless Home Networks (WHNs) suffer from the rate anomaly problem which leads to network performance deterioration. We observe that transmitting bandwidth intensive traffic, such as a video stream, over low data rate links can affect the end-to-end delays of co-existing high data rate traffic. Based on this observation, we propose modifications to the WHN setup. This paper suggests the use of an additional AP to ensure that all nodes transmitting bandwidth intensive traffic to the gateway AP do so at a high data rate or through an intermediate AP. Simulation based evaluation of the proposed network setup shows that in the presence of the rate anomaly problem adding an additional AP improves network wide performance.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Performance

Keywords

WLAN, Rate Anomaly, 802.11

1. INTRODUCTION

The number of Wireless Home Networks (WHNs) are expected to significantly increase in coming years. There are a number of factors contributing to this trend: (1) the increasing availability of broadband connectivity, (2) the increasing number of wireless devices per household, and (3) newer wifi enabled devices such as tablets and smart phones that do not have wired connectivity options. These factors coupled with the ease of setting up a wireless gateway to a broadband connection make WHNs an obvious choice for most homes.

WHNs support a variety of devices and cater for diverse traffic patterns. A home network is made up of devices such as laptops, tablets, VoIP phones, IPTv devices, wireless security cameras, wireless gaming consoles, etc. These devices generate traffic with different properties and different requirements, as shown in Table 1.

Application	Delay	Reliability	Bandwidth
Email	Yes	Yes	No
VoIP	Yes	No	No
Video	Yes	No	Yes

Table 1: This table describes whether a particular application is delay sensitive, requires reliability, and is bandwidth intensive or not.

A typical WHN setup leads to the rate anomaly problem [2]. A WHN typically consists of a single Access Point (AP) which acts as a gateway to a broadband connection. This AP provides connectivity to all the devices in the home and typically runs the 802.11 b, g or n protocol. The devices in a home are, obviously, not all at the same location. Therefore the link quality between the AP and different devices varies according to the device location. This variability leads to different devices communicating with the AP at different data rates. This difference causes unfair access of the wireless medium.

The 802.11 MAC protocol was designed to be packet fair; each node ideally transmits the same number of packets. However, if competing links transmit at different data rates then the link with the lower data rate takes over a larger share of the medium. This can be shown using transmission time calculations. Consider an 802.11g AP with two nodes connected to it. Assume both links transmit 1000 byte packets, one at 54Mbps and one at 18Mbps. We use the following formula to calculate the transmission time $T_{tx}(\mu s) = 26 + \lceil \frac{26+S(bits)}{4*R(Mbps)} \rceil$ [1]; where T_{tx} is the transmission time in microseconds, S is the packet size in bits and R is the data rate in Mbps. Using this formula we observe that, theoretically, the low bandwidth link will consume approximately 68% of the utilized bandwidth. We show that this causes significant increase in end-to-end delay of the high data rate link even when the total traffic is within network capacity. The increase in delay causes loss in performance of real time applications such as IPTv and VoIP.

This paper proposes using multiple access points in WHNs to improve performance of high data rate links in the presence of the rate anomaly problem. We split the low data rate link in to two hops; one from the device to an additional AP and another from the additional AP to the gateway AP. The

MobiWac'11, October 31–November 4, 2011, Miami, Florida, USA.

additional AP is placed in a way to ensure high data rate link between both the APs. We evaluate the performance of the proposed network setup in the presence of video streams, and video streams and VoIP calls. We show that the low data rate link suffers some performance degradation due to the additional hop, but overall network performance is improved.

The rest of this paper is organized as follows. Section 2 provides background information and motivation for the rest of the paper. Section 3 proposes the use of using multiple APs in WHNs and evaluates the performance of multiple APs in different application settings. Finally, Section 4 presents conclusions.

2. BACKGROUND

This section introduces the background required for the rest of the paper. We start by describing the network structure of a typical Wireless Home Network. We then explain how performance is affected due to the rate anomaly problem.

2.1 Network Structure

A typical WHN has a broadband connection that is accessed through a single AP running 802.11 b, g or n protocol. All the mobile devices in the network connect to the Internet through this AP. The traffic generated by different devices varies according to the device. General purpose devices such as laptops and tablets generate diverse traffic ranging from email to video streaming. Special purpose devices such as VoIP phones, wireless security cameras or IPTv devices generate a specific type of traffic.

2.2 Rate Anomaly

The devices in a WHN are dispersed throughout the home and therefore have varying link qualities when communicating with the AP. The varying link qualities lead to different devices communicating with the AP using different data rates. This leads to a phenomenon called the rate anomaly problem [2]. The rate anomaly problem can be demonstrated using a simple example of two links: an AP with two nodes associated with it.

We study two variations of the two link setup. The first is when both the devices are close to the AP and the links have a high SINR. We refer to this scenario as High/High. In the second setup we move one of the nodes further away from the AP so that this node communicates with the AP at lower data rates. We refer to this setup as High/Low.

2.2.1 *Theoretical Evaluation*

The rate anomaly problem causes a transmission time unfairness between competing nodes. This is easy to show using the example of transmission time of two nodes, one transmitting at 54Mbps and the other at 18Mbps (High/Low). The 802.11 MAC protocol is designed to be packet fair; barring any hidden terminals, on average a node transmits one packet and then the other node transmits a packet. However, the setup is unfair in terms of transmissions time. Assuming a 1000 byte packet, the 18Mbps link accounts for 68% of the utilized capacity.

Simulator	Qualnet 4.5
Mobility	None
Capture Model	SINR
Fading	Ricean
Routing	Static
MAC	802.11g
RTS/CTS	Disabled
MAC Retry Limit	7
Data rate selection	ARF

Table 2: Simulation Parameters

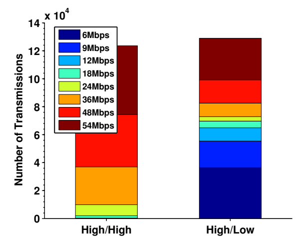


Figure 1: The number of packets transmitted at each data rate of an 802.11g WLAN carrying two video streams. The High/High case represents the setup where both video streams are over a high data rate link and the High/Low case represents the setup where one stream is over a high data rate link and the other is over a low data rate link.

2.2.2 *Simulation Evaluation*

In this section we evaluate the High/High and High/Low scenario using simulations. We evaluate these scenarios using the simulation parameters shown in Table 2.

The traffic used is generated by a 10 minute clip encoded using mpeg-4. We first show that the High/High scenario uses a higher average data rate compared to High/Low. Figure 1 shows the number of transmissions at each of the 8 data rates of 802.11g for the High/High and High/Low scenario. For the High/High case the ARF protocol ensures that most of the packets are sent at higher data rates. For the High/Low case the distribution is more uniform. This is because the High link has more transmissions at higher data rates while the Low link has more transmissions at lower data rates.

Figure 2 shows throughput and delay performance of both the scenarios. The High/Low scenario has a slightly lower throughput compared to High/High. This is because it takes longer for the Low link to get its packets across. However, the difference is not very large since the offered load is within the capacity of the network and the AP is able to maintain a high throughput. However, the end-to-end delay for the two scenarios is very different. The average delay for both the links in the High/Low scenario increases by over 180% compared to the High/High scenario. This can be explained as follows. On average each link transmits one packet alternatively. This combined with the larger transmission times of the Low link means that the High link needs to wait longer between consecutive transmissions. This increases the High links average delay and makes it of the same order as the delay of the Low link. The increased delay can lead to a drop

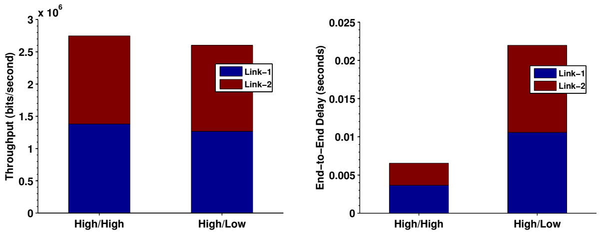


Figure 2: Slight decrease in throughput due to the rate anomaly problem. However, because the low data rate link transmits for a much longer duration, the end-to-end delay is increased significantly for both links.

in user perception of the video due to repeated rebuffering events.

In the next section we propose a change in the network structure to ensure that the High link does not suffer performance degradation because of the Low link.

3. USING MULTIPLE APS

In this section we present a modification to the typical WHN setup to solve the performance issues presented in Section 2.2. We start by explaining the change in the network structure. We then show the theoretical benefit of this approach followed by a simulation based performance evaluation of the multiple-AP approach. We show that by using an additional AP to ensure that all links with the gateway AP are at high data rates we limit the increase in end-to-end delays. Finally, we present a discussion of how a WHN should be structured to ensure better network performance.

3.1 Change in Network Structure

We modify the network structure by adding an additional AP. The extra AP is placed in a way to ensure that nodes with weak links with the gateway AP connect through the extra AP. The additional AP is a multiradio AP so that both APs can be active simultaneously on orthogonal channels. Finally, the extra AP is placed at a location where it has a strong link with the gateway AP.

3.2 Theoretical Evaluation

The benefit of using an additional AP on the performance of the high data rate link, in the scenario in Section 2.2, is obvious. Using the extra AP ensures that none of the nodes communicating with the gateway AP communicate at low data rates. This means that the end-to-end delays of high data rate links do not increase. What we need to evaluate is how much the transmission time of the "Low" link changes since the traffic for this link now has to traverse two hops.

We evaluate this by assuming that instead of communicating with the gateway AP directly at 18Mbps the node with the "Low" link communicates with the extra AP at 24Mbps and the extra AP communicates with the gateway AP at 54Mbps. Again using the formula for transmission time in [1] we calculate that the transmission time of the "Low" link increases by 26%. However, the effect of the "Low" link on the delay of co-existing traffic decreases by over 53%. Therefore, based on calculations the overall network performance is expected to improve.

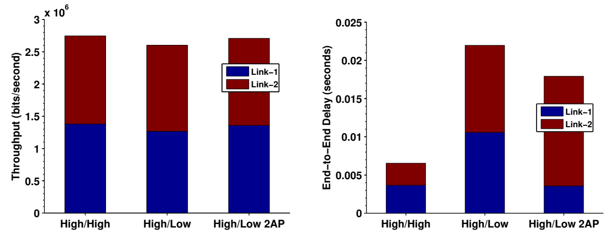


Figure 3: Using Multiple APs prevents performance degradation of high data rate links.

3.3 Simulation Evaluation

In this section we use simulations to evaluate the performance gain of using an additional AP.

3.3.1 Video Streaming

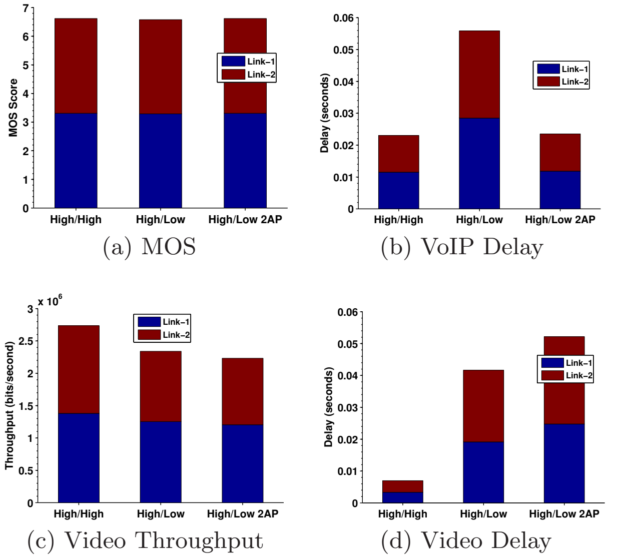
The first case we evaluate is the case with two links described in Section2.2. The performance results for this scenario are shown in Figure 3. The evaluation is for three cases; the High/High and High/Low cases described in Section 2.2 and a third case which is "High/Low 2AP". This third case is the High/Low case with an extra AP placed as described in Section 3.1.

Placing an extra AP in the High/Low case improves network wide throughput and delay. The increase in throughput is small, however, the decrease in delay is significant. The additional AP decreases the end-to-end delay of the High link by over 65% and increases the delay of the Low link by almost 26%. In terms of network wide performance, the end-to-end delay decrease.

3.3.2 Video Streaming and VoIP Calls

Next we evaluate the case with two video streams and two Voice over IP (VoIP) calls. We assume that both the video streams have, on average, similar link quality and hence similar data rates; the same applies for the VoIP calls. There are four possible setups for this scenario. (1) All four links, two for video streaming and two for VoIP, are good quality links. (2) The video streaming links are good quality while the VoIP call links are poor quality links. (3) The video streaming links are poor quality while the VoIP call links are good quality. (4) All four links are poor quality. We assume that some thought is given to the placement of the AP and so the last case never occurs. The second case does not cause much of a performance problem. Recall that the large packet size of video streams combined with low data rate causes an increase in end-to-end delay of high data rate links. VoIP calls generate small sized packets and so, even with lower data rate, they do not cause any significant increase in end-to-end delay of high data rate links. Therefore, we compare the performance of the first and the third case. Figure 4 shows the performance results of the first and the third case and an additional case. This is the "High/Low 2AP" case; the High/Low case with an additional AP.

Figure 4(a) shows that the High/Low case has a small drop in call quality (lower MOS Score). This loss in call quality is recovered by using the additional AP. Using the extra AP to route video traffic causes a significant decrease in VoIP call delay(Figure 4(b)). However, the video stream performance deteriorates because of the extra hop. Although network



(a) MOS (b) VoIP Delay

(c) Video Throughput (d) Video Delay

Figure 4: Using Multiple APs prevents performance degradation of high data rate links.

wide performance improves, video stream throughput falls (figure 4(c)) and video stream delay increases (Figure 4(d)).

3.4 Discussion

The gain in performance of using multiple APs presents guidelines on how a WHN should be structured. Our first observation is that the gateway AP should be placed close to nodes, such as IPTv devices, that run bandwidth intensive applications. This is because if a bandwidth intensive application communicates over a low bandwidth link it significantly affects the performance of other links. Secondly, for cases where bandwidth intensive applications communicating over low data rate links is unavoidable, the use of multiple APs can improve network wide performance.

The bandwidth intensive traffic should be directed through an additional AP so that performance of nodes directly linked to the gateway AP is not affected. Finally, we observe that even in cases where the total offered load is within the capacity of the gateway AP, if bandwidth intensive applications communicate over low data rate link they can increase network wide delays. An additional AP can limit the increase in network wide delays.

4. CONCLUSION

The typical setup of a Wireless Home Network (WHN) gives rise to the rate anomaly problem which, causes unfairness between high and low data rate links. By evaluating a few scenarios we observe that bandwidth intensive traffic over low data rate links caused a 180% increase in the delay of high data rate link traffic. Therefore the presence of one low data rate link can degrade quality of service of all co-existing traffic. In this paper, we proposed the use of multiple APs to improve network wide performance. An additional AP is used to split low data rate links into two hops. This mechanism reduces the delay of high data rate links by 53% at the cost of increasing the delay of low data rate links by 26%. The overall network delay is reduced, thereby improving performance of the high data rate links.

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