PACA: Peer-Assisted Channel Assignment for Home Wireless LANs

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Abstract— **A home network is a residential local area network, in which users are networking their PCs, laptops or wireless multimedia appliances to use a single residential access point (AP) or gateway connecting to the Internet. As network-capable appliances continue to gain momentum in the home, home networks are becoming increasingly popular. The problem arising from the increasing number of "wireless home" is the interference introduced from neighbor's home networks which leads to throughput dropped precipitously. This problem is different from the traditional channel assignment problem in WLAN. We are considering how home wireless network can self-configure its operating channel to minimize interference with other networks instead of how network administrator assigns channel to different APs. In this paper, we propose a peer-assisted channel assignment algorithm, termed PACA, for home wireless LAN based on local information. A newly power on AP automatically configures itself to operate on a channel with least interference. Mobile node helps other APs to do channel assignment and switching dynamically by providing traffic load information. Our simulation and experimental measurements show that the algorithm reduces interference among different networks and improves user throughput.**

I. INTRODUCTION

With the increasing availability of broadband Internet service and affordable PCs, laptops and network-capable appliances, more people are networking their home with wireless technologies. In recent years, people start deploying IEEE 802.11 wireless LANs (WLANs) in home connecting their multiple devices to the Internet. It enables mobile devices to enjoy multimedia application such as playing media from the Internet wirelessly elsewhere in the home, making a wireless multimedia home network.

However, the problem arising from the increasing number of "wireless home" is the interference introduced from neighbor's networks which leads to throughput degradation. It is not unusual to have tens of APs deployed in close proximity of each other. The interference in dense wireless networks can significantly affect user throughput [1].

Home networks are *unplanned* in nature. Unlike traditional WLAN deployments (e.g., campus network), which are carefully designed by network administrators [2], home networks are deployed by *home-users* who are usually *non-network-specialist*. Therefore, we cannot rely on network administrators to do network planning that minimizes interference in the context of home WLAN. In view of the above, there is a need of channel auto-configuration for home APs aiming at selecting an operating channel with least interference.

In this paper, we propose a peer-assisted channel assignment algorithm, termed PACA, for home WLAN based on local information. All the nodes (both APs and clients) record its traffic load continuously. This service (*netstat*) is commonly provided by operating systems including Windows and Linux.

We define two *peer* types of AP. The first type is client of neighboring AP and the second type is neighboring AP. A newly power on AP or an idle AP queries its peers about their traffic information. Nodes in a network also query peer-networks (in other channels) when they are idle. Based on these information, the AP automatically configures itself to operate on the "best" channel. Our approach takes into account the *Hidden Interference Problem* and *Traffic Distribution Problem*, which are discussed in Section III.

PACA is scalable as it is completely distributed. Each AP collects the local information from its peers to do channel assignment. Our main contributions of this paper are the following:

1) We present novel distributed algorithms for channel assignment to minimize interference in unplanned home wireless networks;
2) We implemented PACA and deployed it in real environment;
3) We report the performance study of PACA with both simulation and real measurements. Our results show that networks using PACA encounter much less interference and achieve higher throughput as compared with the traditional widely deployed approach.

The rest of this paper is organized as follows. We present in Section II the related work. In Section III, we present two motivating examples. Peer-assisted channel assignment algorithm is presented in Section IV. In Section V, we discuss the results based on simulation and experimental measurements. We conclude in Section VI.

II. RELATED WORK

We discuss previous related work here. Much work has been done on large-scale WLANs design, which includes optimal

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AP placement, power level assignment and channel assignment (See, for example, [2]–[4]). However, most of these studies assume there are network administrators doing site survey or propagation modeling before WLAN deployment. Our work differs primarily in that we are considering unplanned home WLANs deployment instead of centralized large-scale WLANs.

Mishra *et al.* proposes a dynamic channel assignment algorithm, called *CFAssign-RaC* [5]. This approach is based on a "conflict set coloring" formulation that jointly performs load balancing along with channel assignment. Ahmed *et al.* also proposes an algorithm to solve a simple version of joint channel assignment and power control optimization problem in a successive refinement manner [6]. However, both of them work in a centralized manner and is only suitable for centrally managed networks with multiple APs. As opposed to them, PACA is a fully distributed algorithm and is suitable for multiple independent home WLANs.

Self-management approach in unplanned wireless deployments was proposed in [7]. They show that interference in unplanned 802.11 deployments can significantly affect user performance. They proposed an automated power control and rate adaptation algorithms that reduce network interference. PACA differs by addressing channel assignment problem to reduce interference among networks.

Mishra *et al.* proposes a client-driven approach for channel assignment in WLANs [8]. Their channel assignment approach is based on the interference experienced by clients. However, their algorithm is unable to accurately capture the degree of interference. PACA differs by taken into account the traffic load of APs and clients in channel assignment, which leads to more accurate interference prediction.

III. MOTIVATING EXAMPLES

In this section, we begin by describing the difference between home network and traditional WLAN (Section III-A), followed by a discussion of hidden interference problem in Section III-B. In Section III-C, we present an example of how traffic distribution affects channel assignment decision.

A. Properties of home network

In this section, we illustrate some of the issues arising in multiple home wireless networks deployment. In general, the home WLANs differs from past large-scale WLANs in the following ways:

- *Home user vs network expert:* Unlike large-scale WLANs, home network is usually built by home user (non-specialist) instead of skillful network administrator.
- *Unplanned topology vs planned topology:* For a campus-like large-scale WLAN, the AP placement is carefully determined to minimize channel interference. This can be done by radio frequency site survey. However, the APs placement for home networks are decided by independent home users without prior agreement. So, it is possible that two APs are placed at near position and operate in overlapping channels.
- *Simple management vs advanced management:* Configuration for home WLAN should be as simple as possible. We cannot assume users know how to measure interference and how to change the operating frequency when they encounter interference problem.

In view of the above, to deploy a high performance home network, we need a channel auto-configuration algorithm which is suitable for most home-users. A heuristic to reduce interference from neighboring APs is to assign APs with different "non-overlapping" channels. To enable auto-configuration, each AP scans all channels and chooses a least utilized one as its operating channel. However, this cannot solve the hidden interference problem (Section III-B) and the time-varying traffic distribution problem (Section III-C).

B. Hidden interference problem

Least Congested Channel Search (LCCS) is a common feature provided by commercial wireless access point [9]. It enables user to search for a "least congested" channel. When user encounters problem of throughput degradation precipitously, she may conduct LCCS and configures its home AP to another channel. LCCS is mainly based on scanning by AP. Though it is widely used, however, it is still suffered from the hidden interference problem [8].

We illustrate a hidden interference problem scenario in Figure 1(a), where we show two APs (from different home networks) labeled as AP_1 and AP_2, and mobile nodes labeled as A and B. The circle of a particular node indicates the transmission range of the node. In this scenario, there is no overlapping area of the transmission ranges of AP_1 and AP_2. In other words, they are unable to detect the existence of each other. Therefore, AP_1 and AP_2 configures itself to operate on a random channel or firmware default channel. The two channels are overlapping in high probability [7].

Suppose AP_1 and AP_2 are operating in the same channel. Although the signals of AP_1 and AP_2 do not interfere with each other, it does not mean the two networks do not interfere with each other. In the figure, node A and B is associated with AP_1 and AP_2 respectively. If they start transmitting data via their corresponding AP, they interfere with each other because they fall in the transmission range of each other. LCCS fails to capture this scenario of interference.

A better way is that, every node in a home network tries to detect interference from neighboring networks and feed this information back to its associated AP. In the figure, node A can detect interference created by B. If A can feed this information back to AP_1, it helps AP_1 to make a better channel assignment decision. Our proposed PACA adopts this approach.

C. Traffic distribution problem

Figure 1(b) shows an example topology of four 802.11b home networks. As there is only three non-overlapping channels available (1,6,11), at least two APs need to operate on overlapping channels.

Suppose AP_1 is using channel 1 and A is its associated client, AP_2 uses channel 6 and it has clients B and C, and suppose AP_3 operates in channel 11 and D, E and F are its

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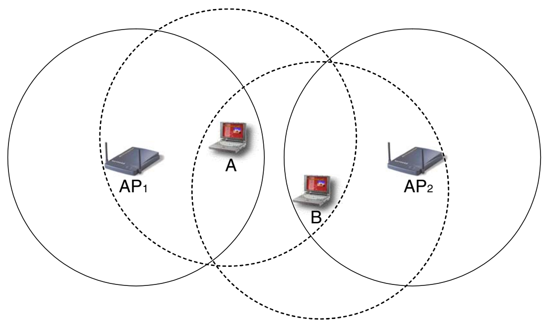
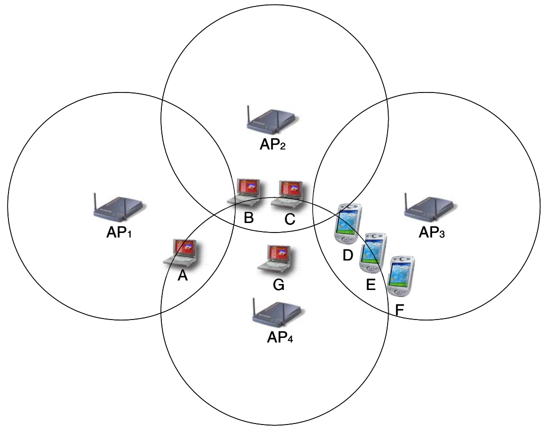


(a) Hidden interference problem.



(b) Traffic distribution problem.

Fig. 1. Two motivating examples for home wireless networks.

client. When G is powered on, it helps its AP (AP_4) to find the least interference channel. It finds that the number of associated clients of AP_1, AP_2 and AP_3 are 1, 2 and 3 respectively. AP_4 then makes a decision to operate in channel 1. However, this is not always correct. Consider a scenario where node A, B and C are running bandwidth demanding applications like real-time video streaming, whereas node D, E and F are running POP3 email client applications. In this case, the interference in channel 11 is much smaller than both 1 and 6. This example shows that, in order to find the least interference channel, traffic load information should be taken into account to capture the degree of interference in a particular channel.

IV. PEER-ASSISTED CHANNEL ASSIGNMENT (PACA)

In this section, we describe the detailed protocol of peer-assisted channel assignment (PACA) algorithm and discuss the channel selection strategy.

PACA is an algorithm which helps AP continuously gather channels information and switches channel when a better channel is needed. When a client in network becomes idle, i.e., it has no communication with the AP, it enters a process called channel utilization query process, which is shown in Algorithm 1. When the client enters the process, it randomly selects a channel (including its current operating channel) and switches to that channel to gather the channel utilization information. In this paper, we assume that AP can only operate in *non-overlapping channels* (e.g., channel 1, 6 and 11 in IEEE 802.11).

Algorithm 1 Channel Utilization Query Process of Client

```
if (No data communication with AP) then
    if (Enters faked PSM and operates in a random channel) then
        Sends CUQuery;
        if (Receives CUReply) then
            Update channel utilization information;
        end if
        if (Time-out) then
            Switches back to original channel;
            Exits faked PSM;
            Receives all the buffered packets;
            Feeds the channel utilization information to AP;
        end if
    end if
end if
```

TABLE I

THE MEANING OF DIFFERENT PEER TYPES.

Peer Type	Meaning
I	Client associated with neighboring AP
II	Neighboring AP

During the switching time, the AP buffers packets destined for the switching node. This can be done by using the Power Saving Mode (PSM) feature available in IEEE 802.11 networks [10]. Switching node will fake PSM to the APs, the AP automatically buffers packets. After the sleep interval, the switching node switches back to original channel and receives all the buffered packets. In this way, there will be no packet loss during the query process.

The switching node broadcasts a *CUQuery* (Channel Utilization Query) when it enters the visited channel. Nodes or APs receiving this query reply the visited node with a *CUReply* (Channel Utilization Reply). The format of the *CUReply* is `<Peer Type, Load>`. The `Peer Type` field stores the type of peer. Table I shows the meaning of different peer types. The `Load` field stores the traffic load (packets/s) of the sender, which is defined as the number of packets sent and received divided by the record interval. If the sender is AP, it means the traffic load of its wireless interface. After the node switching back to original channel, it sends the channel utilization information to AP in the form of `<Channel, Type I Load, Type II Load>`. The `Channel` field stores the visited channel number. The `Type I Load` is the maximum value of `Load` in *CUReply*s received from type I peers. Similarly, the `Type II Load` is the maximum value of `Load` in *CUReply*s received from type II peers.

Each AP independently maintains a *CUTable* (Channel Utilization Table). An example of *CUTable* is shown in Table II. The channel utilization query process of client helps AP to fill the *CUTable*. The `CU` (Channel Utilization Index) is given by

$$\texttt{CU} = \texttt{Type II Load} \times \alpha + \texttt{Type I Load}$$

where $\alpha > 1$. `CU` is a weighted sum of the two loads in different types. The lower the value of `CU`, the better the channel is in terms of interference. We multiply α to

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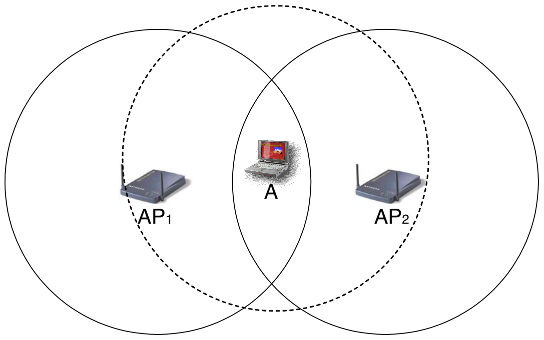
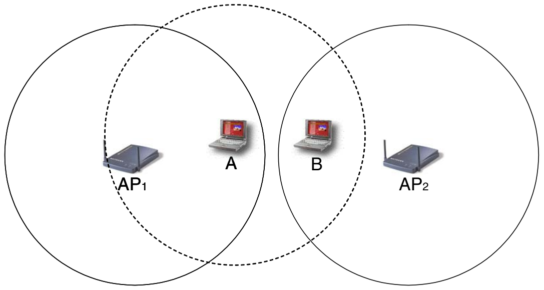


(a) Type II Load.



(b) Type I Load.

Fig. 2. Type II Load implies closer neighboring AP.

TABLE II
THE CHANNEL UTILIZATION TABLE MAINTAINED IN AN AP.

Channel	Type II Load	Type I Load	CU ($\alpha = 10$)
1	45	10	$45\alpha + 10 = 460$
6	0	15	$0\alpha + 15 = 15$
11	0	10	$0\alpha + 10 = 10$

`Type II Load` because type II peers (other APs) potentially introduce larger interference than type I peers. In Figure 2(a), we show two APs labeled as AP_1 and AP_2, and mobile nodes labeled as A. If node A does channel utilization query, it will receive a *CUReply* from a type II peer (AP_2). By simple geometry, this implies that there exists AP which is close to AP_1 in the visited channel. Compare this with the scenario in Figure 2(b), node A can never receive *CUReply* from type II peer because it is outside the transmission range of its neighboring AP. Without loss of generally, we assume closer AP potentially creates larger interference. Therefore, we give higher weighting to `Type II Load` when calculating `CU`.

When AP becomes idle or is newly powered on, it also enters the channel utilization query process similar to that of client. For newly power on AP, it configures its operating channel according to the *CUTable* after the query process. It selects the channel with minimum `CU` to operate. If an operating AP finds that the `CU` of its current operating channel exceeds a certain threshold *TH*, it selects a channel with minimum `CU` in *CUTable* and switches itself to this channel in the next idle time.

V. SIMULATION AND EXPERIMENTAL MEASUREMENT RESULTS

To evaluate the performance of PACA, we have performed detailed simulation using NS-2 network simulator, implemented PACA and conducted real measurements on it. In this section, we first present illustrative results on PACA performance based on simulation (Section V-A), followed by our experimental setup and measurements (Section V-B).

TABLE III
SIMULATION SETTINGS.

Transmission Range	250m
Radio Propagation Model	Two-ray Ground
Medium Access Protocol	IEEE 802.11 DCF
Link Data-Rate	2 Mbps
Simulation Duration	200s
Traffic Type	Constant bit rate (CBR) of 64 kbps
Packet Size	512 bytes
Number of channels	3 (non-overlapping)
α	10
TH	500

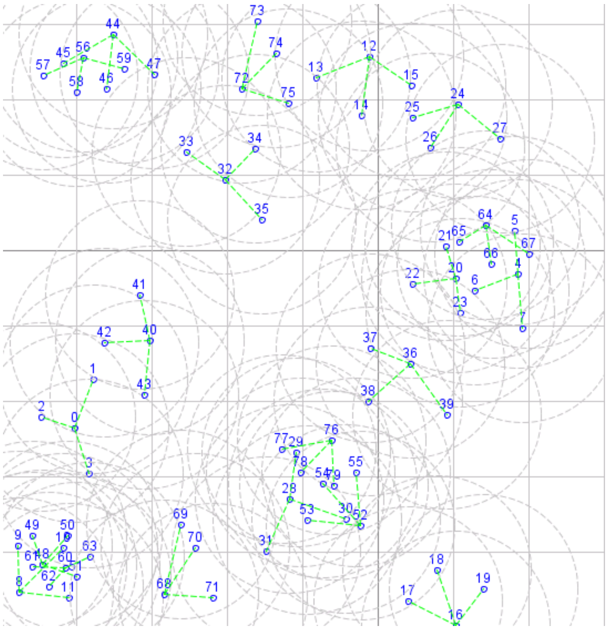
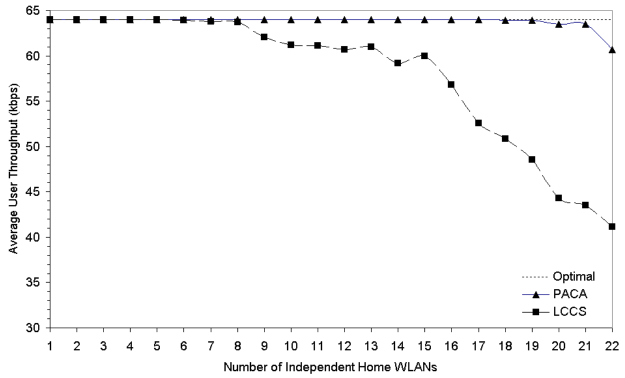


Fig. 3. A simulation run snapshot.

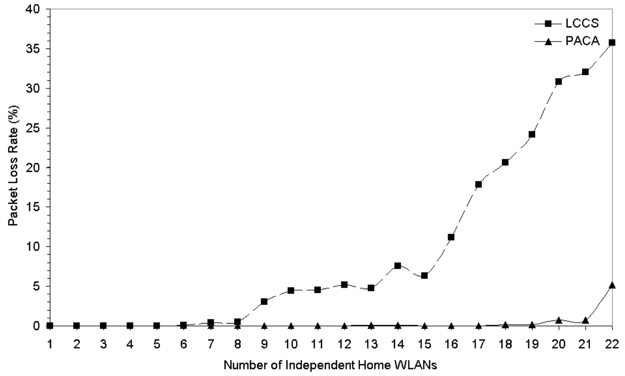
A. Illustrative Simulation Environment and Results

We use NS-2 (version 2.27) to simulate PACA. The parameters for all the simulation runs are listed in Table III. We model home WLAN by one AP and three associated clients. We randomly put different numbers of home WLANs in a square of size 1600m × 1600m. The generated traffic is UDP (constant bit rate of 64kbps) and all traffic are from AP to clients in its own WLAN. Figure 3 shows a snapshot of one of our simulation runs. In the figure, if a node ID is divisible by 4, it is an AP of a WLAN and it is connected to its client by a straight line. The circular area centered at a particular node indicates its transmission range. As the home WLANs are randomly put in the square, there is a lot of overlapping area. This can be viewed as an unplanned WLAN which consists of many independent home WLANs interfering with each others.

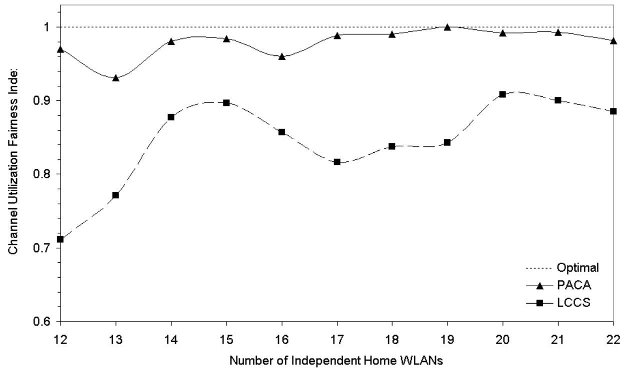
We compare PACA and LCCS in Figure 4(a) in terms of average user throughput against number of independent home WLANs. For both algorithm, the average user throughput



(a) Average user throughput against number of independent home WLANs.



(b) Packet loss rate against number of independent home WLANs.



(c) Channel utilization fairness index against number of independent home WLANs.

Fig. 4. Performance comparison between PACA and LCCS.

decreases with the number of independent home networks due to interference. For small number of independent networks, the throughput achieved by PACA and LCCS are roughly the same and reaches the maximum throughput. As the number of networks increases, LCCS fails and the user throughput decreases sharply. This is because LCCS fails to capture the changing traffic information of different channels. It leads to undesired channel assignment. Users in some region are therefore experience very high interference, leading to throughput degradation. In contrast, PACA consistently achieves high level of average user throughput due to its continuous update.

We also compare in Figure 4(b) the packet loss rate between the two methods. The packet loss rate increases with the

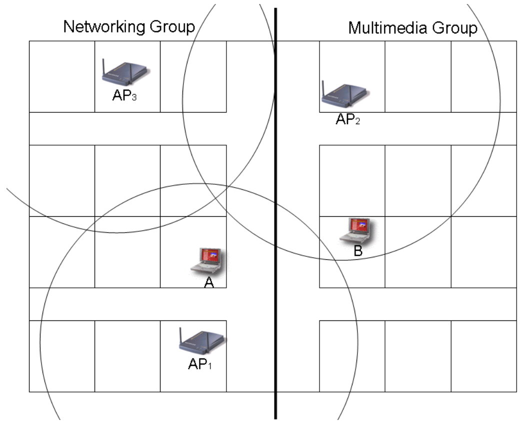


Fig. 5. Experimental setup on the Multimedia Technology Research Center at HKUST.

number of networks. As PACA can capture the updated traffic information in different channels and avoid the hidden interference problem, the packet loss rate of networks with PACA is much smaller than networks with LCCS.

We compare in Figure 4(c) the fairness of channel utilizations with the number of independent networks. The channel utilization fairness index, F, is defined by

$$F = \frac{\left[\sum_{i=1}^{n} l_i\right]^2}{n \sum_{i=1}^{n} {l_i}^2},$$

where l_i is the traffic load at channel i, and n is the total number of available channels (3 in this case). F approaches to 1 when the traffic load in each channel approaches equality. Due to the use of channel utilization table in PACA and the continuous update of traffic load information, the load distribution in different channels is much more uniform as compared with LCCS.

B. Experimental Setup and Measurement Results

We have implemented PACA in Linux and carried out experimental measurements to validate the performance benefit of PACA. We quantify the benefit of channel assignment on home WLAN in terms of data throughput.

We conduct our experiments on the Multimedia Technology Research Center (MTrec) at the Hong Kong University of Science and Technology (HKUST). Figure 5 shows the floor plan of the experimental environment. The network consists of three APs labeled as AP_1, AP_2 and AP_3 where approximate coverages are indicated as circles.

AP_1 and AP_2 belongs to the Networking group and Multimedia group of MTrec respectively. AP_3 is installed by HKUST and is not manageable. The nodes labeled as A and B are laptops with Intel Pentium III 650 MHz processor and 128 MB RAM. They equipped with Cisco Aironet IEEE 802.11b wireless PCMCIA card. A and B are associated with AP_1 and AP_2 respectively. They are Cisco IEEE 802.11b APs running on the firmware default configuration. We use Wireless

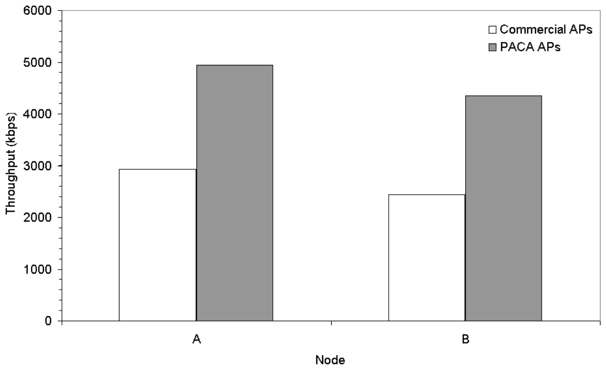


Fig. 6. Comparison of the FTP throughput between PACA and LCCS.

Tools [11] to check the operating channels of the three APs. Surprisingly, they are all operating in channel 6. This again shows that independent home WLANs need a channel auto-configuration protocol in order to reduce interference.

An FTP server is connected to the same LAN of AP_1 and AP_2. We measured the total transfer time of downloading a 57.6MB video file from the FTP server by A and B concurrently. The data transfer statistics were obtained from the Linux Arpanet FTP program.

As we cannot modify the firmware of the two Cisco APs, we implement PACA algorithm on two IBM laptops with Ethernet adapter. For wireless connectivity, Cisco Aironet IEEE 802.11b WLAN cards are used. We place this two "APs" at the same locations of the Cisco APs. The Cisco APs are turned off during the measurement of PACA.

With PACA, AP_1 and AP_2 quickly self-configures to operate in channel 1 and 11 respectively, hence reducing the interference among networks. On the other hand, with commercial APs, the operating channels do not change dynamically. AP_1 and AP_2 stays in their default channels. Figure 6 compares the nodal FTP throughput between network using PACA and commercial APs. Node A and B accesses the FTP server concurrently. When using cisco APs, the FTP throughput is low due to the large interference between A and B. As PACA makes the two APs operate in two non-overlapping channels, the FTP throughput is therefore much higher.

VI. CONCLUSION

Peer-Assisted Channel Assignment (PACA) overcomes the weakness of commonly deployed LCCS algorithm in channel assignment and switching for unplanned home WLANs. It is a completely distributed and scalable algorithm.

Node using PACA gathers the traffic information from other networks with the help from *peers*. This information helps AP capture the traffic information of other available channels, which enables better channel assignment and switching.

We validate the performance benefit of PACA both in simulation and experimental measurement. As compared with LCCS, PACA achieves much better performance in terms of network throughput, packet delivery rate, and channel fairness.

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