IEEE 802.11n Based Wireless backhaul Enabled by Dual Channel IPT (DCH-IPT) Forwarding

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Abstract

Wireless backhaul has received much attention as an enabler of future broadband mobile communication systems because it can reduce deployment cost of pico-cells, an essential part of high capacity system. A high throughput with a minimum delay network is highly appreciated to sustain the increasing proliferation in multimedia transmissions. In this paper, we propose a backhaul network using the Multi-Input Multi-Output (MIMO) IEEE 802.11n standard in conjunction with the Dual Channel Intermittent Periodic Transmit IPT (DCH-IPT) packets forwarding protocol. By using these two techniques (IEEE 802.11n + DCH-IPT), wireless backhaul nodes can meet more demanding communication requirements such as higher throughput, lower average delay, and lower packet dropping rate than those achieved by the currently used backhaul. The current backhaul is based upon Single-Input Single-Output (SISO) IEEE 802.11a,b,g standards in conjunction with Single Channel Conventional (SCH-Conv) relaying protocol in which packets are transmitted continuously from source nodes using single channel. The proposed backhaul will accelerate introduction of picocell based mobile communication systems.

Keywords: Wireless Backhaul Networks, IEEE 802.11n, IEEE 802.11a, MIMO-OFDM, IPT forwarding.

1. INTRODUCTION

Wireless backhaul is a wireless multihop network in which base nodes are linked wirelessly [1] [2]. Wireless backhaul has received much attention as an enabler of future broadband mobile communication systems because it can reduce deployment cost of pico-cells, an essential part of high capacity system. A high throughput with a minimum delay network is highly appreciated to sustain the increasing proliferation in multimedia transmissions. In wireless backhaul, base nodes have capability of relaying packets, and a few of them called core nodes serve as gateways connecting the wireless multihop network and the outside network (i.e. the Internet) by cables. Although wireless backhaul has many attractive features over wired backhaul networks like ATM, T1 or DSL line, it is still lack for high throughput design [3]. Recently, researchers in the field of wireless multihop try to improve its performance using MIMO [4-7].

One of the advanced wireless standards driven by MIMO technology is IEEE 802.11n (Dot11n) [8]. Dot11n is an amendment, proposed by a group in IEEE802.11 committee called TGn group, over the previous OFDM based 802.11 standards (802.11a/g) (Dot11a/g) with PHY and MAC enhancements [8] [9]. Using different space time code structures, the Dot11n's MIMO-OFDM can support data rates up to 600 Mbps which is higher than IEEE 802.11a/g (SISO standard) data rate (54 Mbps at maximum). In order to take the full advantage of Dot11n, TGn also enhances its MAC layer by introducing new frame structures that can be used to aggregate multiple subframes to improve throughput [9]. In [9], the authors extensively studied the IEEE 802.11n MAC aggregation mechanisms and their effects upon the IEEE 802.11n throughput performance.

Because Dot11n is in small age, an adoption of the interface to wireless multihop is in its infancy [5] [6]. Some studies concerned about investigating more efficient MIMO-based MAC protocol than the Dot11n's one so as to be suitable for Ad-Hoc and Wireless Mesh Networks [6] [7]. Others concerned about improving the IEEE 802.11s performance, an IEEE 802.11 standard for Wireless Mesh Networks (WMN), by using Dot11n based mesh nodes [5]. To do that, the authors in [5] first utilize the variable transmission rate property of Dot11n to find the best PHY data rate related to instantaneous channel quality, then by using this data rate, they find the best MAC aggregation number that guarantees low packet dropping rate, At last, they use theses two settings (PHY rate + MAC aggregation number) to optimally allocate bandwidth to each type of traffic [5]. According to the authors' knowledge, most of the studies adopted Dot11n utilizes its MAC and PHY enhancements to improve the performance of Wireless Mesh Networks (WMN) and Ad-Hoc networks, whereas few proposals concerned about adopting the standard to wireless backhaul. Even though all the three networks can be categorized as a wireless multihop network, wireless backhaul is the only one that can accept static tree topology routing. This is because all the nodes are fixed in their positions and all uplink and downlink packets are distributed to entire backhaul network via core nodes. Hence, the static tree topology routing is the ratified topology for the predominantly fixed infrastructure networks like wireless backhaul networks, and it is chosen for the IEEE 802.11s in case of fixed Mesh Point Portal MPP (core node in case of wireless backhaul). This can be found in the IEEE 802.11s draft, and extensively explained in [10]. On the other hand, dynamic mesh routings are preferred for WMN and Ad-Hoc because of the specific structure of these networks, i.e. multi-point to multi-point connections among all neighboring nodes and dynamic changes of nodes positions. The difference between the two routings is shown in Fig. 1. In wireless backhaul with a static tree topology routing, since we can reduce the number of intersections on its routes as found in Fig. 1, each node can maintain fewer number of connecting nodes, which will contribute to reduce complexity in necessary processes relating to MIMO signal detection, such as synchronization, channel state acquisition and so on. This feature in wireless backhaul will deliver us a larger benefit of the Dot11n adoption compared with other wireless multihop networks, i.e., WM and Ad Hoc networks.

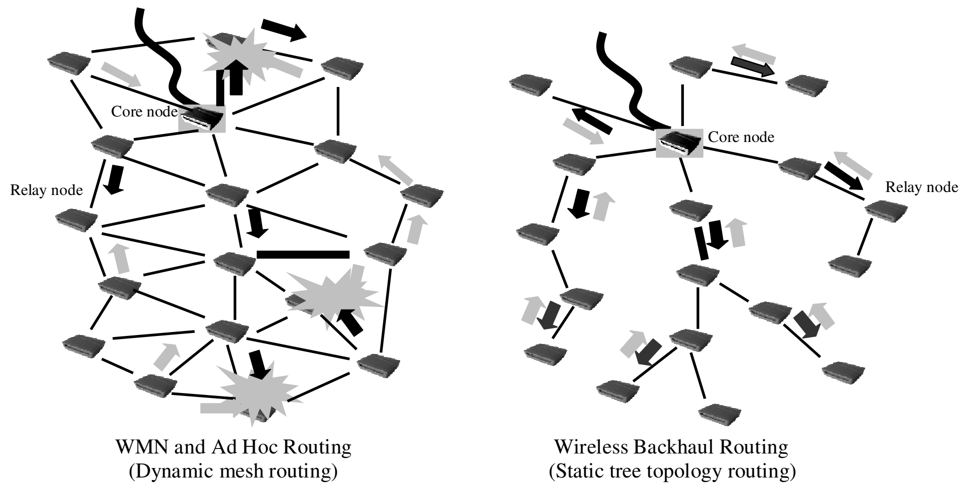


FIGURE 1: WMN and Ad Hoc Routings versus Wireless Backhaul Routing.

The application of Dot11n as MIMO wireless interface to wireless backhaul with static tree topology to enhance throughput and spectrum efficiency of its relay network was given by the authors in [11] and [12]. In this proposal, the authors compared the effectiveness of Dot11n and Dot11a based wireless backhauls under same transmission rates and bandwidth. They proved that Dot11n based wireless backhaul has higher throughput, lower average delay, and lower packet dropping rate than Dot11a based one although of the same transmission rates. In addition, they proved the robustness of Dot11n-wireless backhaul performance even in highly correlated MIMO channels environment. At the end of the research, they further improved Dot11n-wireless backhaul performance through utilizing the single channel IPT (SCH-IPT) forwarding protocol.

For further research development on the Dot11n based wireless backhaul given by the authors in [11] and [12]. And, in analogy to the IEEE 802.11 MAC enhancements to be more compatible with Dot11n high transmission rates [9], this paper concerns about studying Dot11n in conjunction with packet forwarding protocol issues for wireless backhaul, i.e., finding an appropriate packet forwarding protocol suitable for Dot11n to produce highly efficient wireless backhaul. To cope with this issue, we propose the Dual Channel relay (DCH) protocol for Dot11n transmission. Rather than Single Channel (SCH) forwarding protocol in which single channel is used for both uplink and downlink packets transmissions, our proposed Dual Channel (DCH) forwarding protocol uses two different channels for packets transmissions; one channel for uplink transmissions and the other for downlink. Therefore, fast with low interference relay is produced. Using this DCH scheme, packets are transmitted faster than using SCH because in the proposed DCH there is no waiting time between the two kinds of transmissions. Instead, simultaneous transmissions are used. In addition, this protocol mitigates the nodes congestion problem due to heavy uplink and downlink traffic. Also, using the proposed DCH forwarding protocol, two different forwarding protocols can be used for each packet type, i.e. uplink or downlink depending upon the traffic conditions [13][14], which will increase the reliability of the scheme and further fast the relay. All these DCH advantageous get it compatible with Dot11n more than SCH in which delay and interference withstand the full utilization of the high transmission rates (up to 600 Mbps) supported by Dot11n results in a low throughput performance. Dual channel strategy is used by many wireless multihop researchers in order to modify the IEEE 802.11 MAC protocol (initially designed for WLAN) to be more suitable for wireless multi-hop networks [15]-[18]. Although these Dual channel MAC protocols solve many of the IEEE 802.11 based multi-hop networks problems (hidden node, exposed node, receiver blocking, intra-flow, and inter-flow), packet transmissions from hop nodes are still one direction basis (uplink or downlink at a time). Hence, any multi-hop node can’t transmit in both directions (uplink and downlink) simultaneously. So, a big transmission delay exists in addition to the nodes congestion problem in case of heavy uplink and downlink traffic. Also, high packet dropping rate occurs due to opposite direction packets collision.

These problems are solved by our proposed DCH scheme results in a high utilization of the Dot11n high transmission rates. To prove the efficiency of the proposed DCH forwarding protocol, we compare the throughput performance between Dot11n-SCH-Conv and Dot11n-DCH-Conv in which conventional (Conv) method of relaying is used for both schemes. In contrast to the Intermittent Periodic Transmit (IPT) protocol [13], in which packets are transmitted from source nodes with a predefined transmit period, in conventional method packets are transmitted continuously from the source nodes. Also, we compare the throughput performance between Dot11a-SCH-Conv and Dot11a-DCH-Conv. The obtained results show a much better throughput performance of DCH-Conv than that achieved using SCH-Conv. In addition, simulation results ensure higher computability of DCH-Conv forwarding protocol to Dot11n (MIMO) than Dot11a (SISO) transmission. Based upon these achievements, we suggest the DCH-IPT, which is based on our previous work on wireless backhaul networks with static tree topology routing [13] [14], as a forwarding protocol suitable for Dot11n (MIMO) transmission. The combination of Dot11n and DCH-IPT produces more efficient wireless backhaul than that obtained by combining Dot11n and DCH-Conv.

The rest of the paper is organized as follows. Section 2 describes the IPT forwarding protocol. Section 3 describes the proposed DCH-IPT in more details. The simulation scenarios and performance metrics are given in section 4. Section 5 gives a comparison between SCH-Conv and DCH-Conv using Dot11a and Dot11n. A comparison between DCH-IPT and DCH-Conv under Dot11n environment is given in section 6 followed by the conclusion in section 7.

2. THE INTERMITTENT PERIODIC TRANSMISSION IPT FORWARDING

The IPT protocol is an efficient packet relay method with which a constant throughput irrespective of the node counts can be obtained [13]. Figures 2 and 3 clearly explain the difference between the conventional CSMA/CA (Conv) relaying method and IPT forwarding. In these figures, 9 nodes are linearly placed. In case of the Conv method, the source node sends packets with a random transmission period of P_Conv, i.e., as the packet appear at the source node it is immediately go through the transmission schedule, and each intermediate relay node forwards received packets from its preceding node with a random backoff period. In the case of IPT, the source node transmits packets intermittently with a certain transmission period of P_IPT and each intermediate relay node immediately forwards the received packets from the preceding node without any waiting period. In the conventional method co-transmission space, which is defined as the distance between relay nodes that transmit packets at the same time, is not fixed. In such situation, packets collisions could occur due to co-channel interference if the co-transmission space is shorter than the required frequency reuse space, as shown in Fig.2. On the other hand, in case of the IPT forwarding it can be readily understood that the co-transmission space could be controlled by the transmission period P_IPT that is given to the source node, as shown in Fig.3 in which reuse space is assumed to be 3. Reduction of the packet collisions will help to reduce re-transmissions and will consequently help to improve the system performance. In [14], the authors proposed an adaptive IPT duration in order to remove interference between co-channel relay nodes and maximize resultant throughput observed at the destination node. Figure 4 schematically shows the normalized throughput versus hop count feature of the conventional method and IPT forwarding for the systems in Fig.2 and 3. In Fig.4, constant IPT duration is applied for all slave nodes and thus the resultant throughputs are all the same [13].

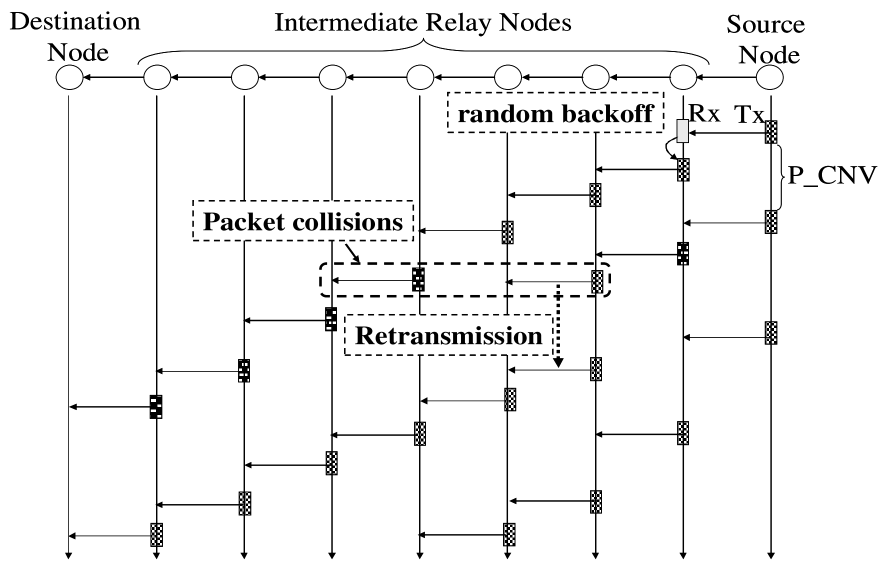


FIGURE 2: Packet relay in conventional method.

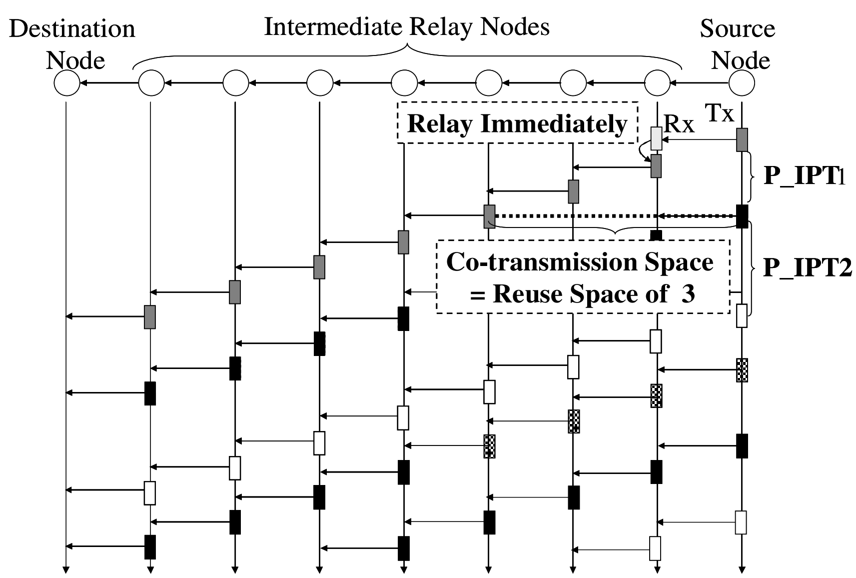


FIGURE 3: Packet relay in IPT method.

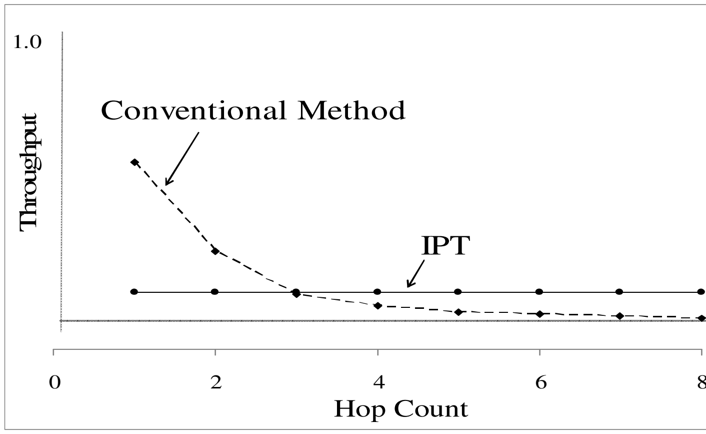
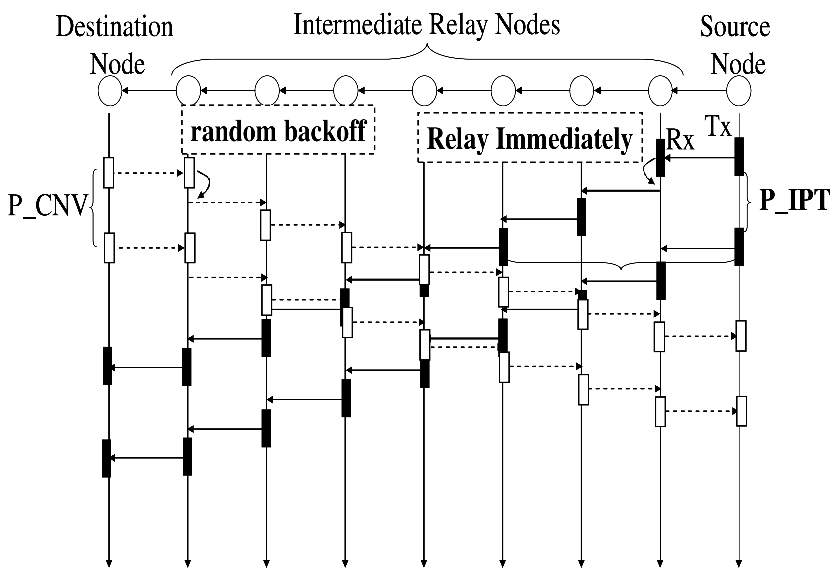


FIGURE 4: The performance comparsion between conventional method and IPT forwarding.

3. THE DUAL CHANNEL IPT (DCH-IPT) FORWARDING

As explained in the previous section, IPT forwarding is best suited for wireless backhaul networks with static tree topology routing (our main concern), where there are few number of intersections between nodes in which IPT can work efficiently. Also, the idea of IPT forwarding relies on one-way traffic either uplink or downlink transmission at a time using the same channel with predefined transmission duration of P_IPT, by which relay efficiency can be maximized. Hence, in case that downlink and uplink packets are duplexed on a single route, packets from one direction collide with ones from the other direction, which would spoil the benefit of the intermittent period transmit, and prevents the scheme from fully exploiting the high transmission data rate of Dot11n and MIMO in general. To cope with this problem and to adapt the current IPT protocol with the high data rate Dot11n-based nodes and produce high speed backhaul, we investigate the Dual-Channel IPT (DCH-IPT) relaying protocol. In this protocol, we assign two channels to transmit the relying packets simultaneously. One for uplink packets transmissions and the other for downlink packets transmissions. Figure 5 shows the DCH-IPT protocol using channel 1 for uplink packets transmissions and channel 2 for downlink packets transmissions. In this figure, we choose IPT protocol to transmit downlink packets and conventional method to transmit uplink packets. This is because downlink traffic is always heavier than uplink traffic, and IPT is more efficient than Conv method when the traffic is heavy [13]. Otherwise, when both uplink and down link traffic are heavy, IPT can be used for both kind of traffic. This flexibility will contribute in producing fast reliably relay.

Our proposed DCH-IPT can be implemented by assigning two different interfaces (radios) per relay node, one for uplink transmissions and the other for downlink transmissions, and each radio is tuned to a different channel. These two assigned channels are separated so as there will be no interference between each type of transmissions. This implementation ultimately reduces the cost of the scheme thanks to cheap Dot 11n interfaces. Although DCH-IPT uses 2 radios with double bandwidth compared to single channel IPT SCH-IPT (single radio using single channel), it contains some interesting features which get it compatible with Dot11n. By using this scheme, relay node can transmit on both channels at the same time, so we can efficiently exploit the Dot11n high transmission capability without any delay resulting from the relaying protocol. In addition, and by using this scheme, we can exploit two different relaying protocols one for each channel in relation to traffic conditions, which further improves the relay. For example, if the traffic is low, it’s better to use conventional method over IPT and vice versa [13]. So by using this flexibility, we can produce a highly efficient relay. Also, packet collisions are extremely reduced through DCH-IPT. So, DCH-IPT has a much lower interference than SCH-IPT which when combined with Dot11n greatly enhances relay performance in terms of higher throughput, lower average delay and lower packet dropping rate. As a result, DCH-IPT produces a fast and efficient wireless backhaul when combined with Dot11n.



→	Downlink Packets
⋯→	Uplink Packets

FIGURE 5: The Dual Channel IPT (DCH-IPT) forwarding.

4. SIMULATION SCENARIOS AND PERFORMANCE METRICS

To evaluate the performance of the suggested Dot11n-DCH-IPT wireless backhaul network and prove its efficiency, we evaluate PHY layer Bit Error Rate (BER) using the MATLAB program which utilized by our original network simulator to evaluate the whole network performance.

4.1 Simulation Scenarios and Parameters

4.1.1 PHY Layer

In order to prove the effectiveness of using DCH relay with Dot11n over using DCH relay with Dot11a, we compare the performance of the two PHY layers

- **IEEE 802.11n** (MIMO standard)**.**
- **IEEE 802.11a** The currently used (SISO standard)**.**

We evaluate Dot11n and Dot11a PHY performances under the following transmission rates: Dot11a 54Mbps, Dot11n 36Mbps, 48Mbps and 60 Mbps. The IEEE 802.11n 60Mbps uses high throughput specifications.

Table 1 shows Dot11n and Dot11a PHY layers simulation parameters.

Parameter	Dot11n	Dot11a
Number of Data Subcarrier	48/(108)	48
IFFT Size	64/(128)	64
Cyclic Prefix length	16	8
Pilot Subcarriers/ Symbol	4/(6)	4
QAM mapping	QPSK-16QAM/(16QAM)	64 QAM
Transmitter antennas	2	1
Receiver antennas	2	1
FEC Rate	¾, 0.5/(0.5)	¾
Raw Data Rates	36, 48 M/(60Mbps)	54 Mbps
MIMO Detector /channel equalizer	SOMLD (Soft Output Maximum Likelihood)	
Channel Estimation	Perfect	
Synchronization	Perfect	
Quasi-Static Channel model Rayleigh fading (NLOS) with exponential PDP (Power Delay Profile) indoor or outdoor (large open space) case T_{max}(MAX delay spread)=300ns, T_{rms} (RMS delay spread)=150ns		

TABLE 1: PHY layers parameters

4.1.2 MAC Layer

For MAC operation, the operation mode of CSMA/CA, the MAC standardized by IEEE 802.11, dynamically changes in between the Basic and RTS/CTS modes depending on message transmit method and IPT activation: when IPT forwarding is carried out, the Basic mode is applied otherwise the RTS/CTS mode is chosen. When the simulator is turned to evaluate the Dot11n 60Mbps performance, a 4-packet A-MSDU MAC aggregation is used [9]. Otherwise in the Dot11n 36 and 48 Mbps non high-throughput modes, no packet aggregation is used.

4.1.3 Traffic Model

Downlink traffic directed to terminals that stay under base nodes is all generated at a core node and forwarded to each base node. Uplink traffic caused by terminals is gathered at the base node in which the terminals stay and forwarded to a core node. The Poisson process is employed as a traffic model. The number of data packets per session is randomly determined by the log-normal distribution, the mean of which is 20 for downlink and 3 for uplink. The ratio of the total offered load of downlink to uplink is 10:1 [19].

4.1.1 Packet forwarding methods

In order to prove the efficiency of DCH-Conv wireless backhaul over SCH-Conv, and also, in order to prove the efficiency of DCH-IPT over DCH-Conv, we compare the following relaying methods with the same forwarding path shown in Fig 4.

- **SCH-Conventional method (SCH-Conv)-** packets are transmitted continuously, using single channel for both uplink and downlink transmissions, with minimum path loss with RTS/CTS MAC mode for all transport sessions.
- **DCH-Conventional method (DCH-Conv)-** packets are transmitted continuously, using two channels one for uplink and the other for downlink transmissions, with minimum path loss and RTS/CTS MAC mode for all transport sessions.
- **Dual Channel IPT (DCH-IPT) protocol-** in this scheme, we use IPT protocol with basic mode MAC for downlink packets, and conventional method with RTS/CTS MAC for uplink

packets. We use the conventional method for uplink packets because the conventional method is better than IPT when the traffic is low [20].

4.1.5 Evaluation Site

We chose the floor of our department building as a test site Fig 6. In order to handle a complex interference situation as correctly as possible, we use a simple deterministic radio propagation model such as a path loss coefficient of 2 dB until 5m and 3.5 dB beyond this distance [21], 12 dB penetration loss of the wall [22]. 23 base nodes are placed on the floor and a core node is placed on stairs area of the floor Fig 6. A forwarding path is formed in advance and fixed during simulation Fig 6.

Spectrum assigned to the wireless repeater network is assumed to be different from one assigned to wireless communication links between mobile terminals and base station (access network), so interference between access network and repeater network can be excluded.

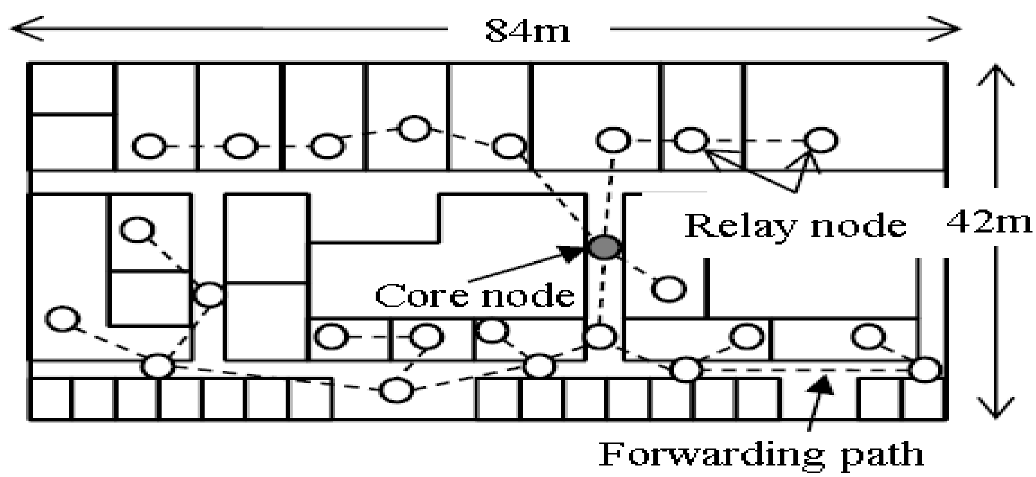


FIGURE 6: Floor plan and node layout for evaluations.

4.2 Performance Metrics

4.2.1 PHY Layer Simulator

We evaluate the BER (Bit Error Rate) performance of each tested PHY layer, i.e., Dot11a 54, Dot11n 36, 48, and 60 Mbps.

4.2.2 System Level Simulator

Three performance metrics are used: Aggregated end-to-end throughput, Average delay, and packet loss rate.

a. ***Aggregated end-to-end throughput*** is defined as sum of throughputs for all sessions each of which successfully delivered to a destination.
b. ***Average delay*** is defined as an average time period from the instant when a packet occurs at a source node to the instant when the destination node completes reception of the packet.
c. ***Packet loss rate*** is defined as follows:
   Packet loss rate [%] =*ND*100 / (NS +ND).*
   Where *NS* denotes the number of packets received successfully by destination nodes.
   ND denotes the number of discarded packets due to exceeding a retry limit

Each simulation is carried out for 200 sec; this simulation period has been ensured to achieve a good convergence. Also, we assume UDP traffic.

5. COMPARISON BETWEEN SCH-CONV AND DCH-CONV USING DOT11A AND DOT11N

Mont Carlo simulations are carried out for evaluating the comparison between SCH-Conv and DCH-Conv based wireless backhauls.

5.1 PHY Layer Simulator

Figure 7 shows the BER performance of the compared PHY layers (Dot11a 54 Mbps and the high-throughput Dot11n 60 Mbps). Form this figure; we notice the extremely enhanced BER performance of Dot11n over Dot11a counterpart although of nearly same transmission rate. This Dot11n better BER performance comes from using multiple antennas at both transmitter and receiver (MIMO) which is not the case for Dot11a (SISO). By using MIMO, Dot11n uses lower MCS (Modulation Coding Scheme) than Dot11a to obtain the same transmission rate under the same bandwidth. For example, in order to obtain a transmission rate of 36 Mbps for both Dot11a and Dot11n under the same bandwidth of 20 MHz, Dot11a uses 16-QAM with FEC=3/4, but 2x2 MIMO Dot11n uses QPSK with FEC=3/4. This Dot11n's MCS reduction resulting from using MIMO greatly enhances its BER performance.

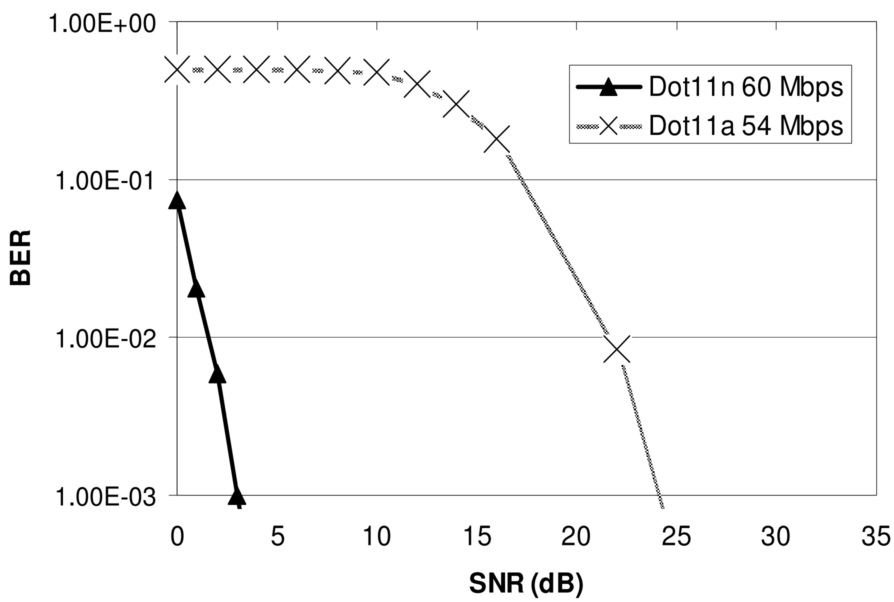


FIGURE 7: BER performances of Dot11n and Dot11a.

5.2 System Level Simulator

Using the BER performances of Dot11a 54 Mbps, Dot11n 60 Mbps evaluated in section 5.1, we compare their system level performances using SCH-conventional and DCH-conventional methods of relaying. Figure 8 shows the aggregated end to end throughput resulting from this simulation.

First, we notice that the throughput performance of Dot11n 60-SCH-Conv is about 50% larger than Dot 11a 54-SCH-Conv although Dot11n 60 transmission is only 6Mbps higher than Dot11a 54 transmission. This Dot11n higher performance comes from its better BER performance as explained in section 5.1. Better BER performance means that for a certain required PER (Packet Error Rate) performance value, Dot11n operates at a lower SINR (Signal to Interference Ratio) value than Dot11a, which gives Dot11n robust characteristics against interference, i.e., Dot11n has a higher tolerance to interference than Dot11a. This important Dot11n phenomenon has a great impact on system performance in which interference causes a significant degradation in performance. In addition, the MAC Aggregation process used in Dot11n, which is not Dot11a case, causes a lower network delay than that occurred using Dot11a especially for high Dot11n rates like 90, 180Mbps, etc. These facts are reflected on the system level performance in terms of higher throughput than that achieved by Dot11a based one as revealed by this figure. These simulations support the idea of enhancing wireless backhaul performance using Dot11n-based nodes previously stated by the authors [12].

In addition, from this figure, we can notice the improved performance of the Dot11a 54-DCH-Conv / Dot11n 60 DCH-Conv over the Dot11a 54-SCH-Conv / Dot 11n 60-SCH-Conv respectively. This improved DCH-Conv performance comes from using two channels relaying protocol, one for uplink and the other for downlink packets transmissions, which fasts the relay compared to the SCH-Conv relay, in which uplink or downlink packets can be transmitted at a time. Also, by using Dual Channel technique, their will be less interference occurred between uplink and downlink packets which contributes in enhancing the wireless backhaul performance.

Furthermore, it is clear that the achieved throughput improvement using Dot11n-DCH-Conv is about twice the achieved improvement using Dot11a-DCH-Conv. This is because Dot11n has a better PER (Packet Error Rate) than Dot11a in addition to the MAC Aggregation scheme used in Dot11n. These features require a low interference environment to work efficiently. Dual Channel protocol has lower interference than Single Channel one, where uplink and downlink packets collisions greatly affect Single Channel performance. So, the combination of Dot11n and Dual Channel protocol gives us a much better achieved performance improvement than that achieved by combining Dot11a and Dual Channel protocol.

In conclusion, Dot11n (MIMO+MAC Aggregation) is a promising wireless interface in enhancing the wireless backhaul performance which requires a good relaying protocol that can fully exploit this powerful interface. Dual Channel relaying protocol is the convenient relaying protocol which when cooperates with Dot11n extremely enhances wireless backhaul performance.

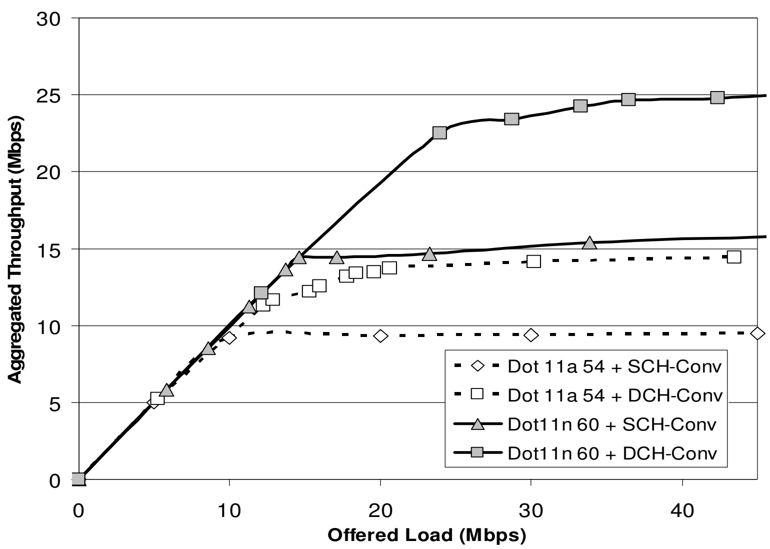


FIGURE 8: Comparison between SCH-Conv and DCH-Conv under Dot11a and Dot 11n.

6. COMPARISON BETWEEN DCH-IPT AND DCH-CONV USING DOT11N

In these simulations, by using the BER of the non high-throughput Dot11n 36 and 48Mbps shown in Fig 9, we compare the system level performances of theses PHY layers with DCH-Conv and DCH-IPT relaying protocols. Figures 10-12 show the aggregated end-to-end throughput, Average Delay, and Packet Loss rate of this comparison. The simulation results ensure better performance of the DCH-IPT based network over DCH-Conv based one. About 20 % improvements in throughput and average delay result from using DCH-IPT relaying. In addition, the packet dropping rate is extremely enhanced, about 10^{-3} reduction in packet loss rate. This enhanced DCH-IPT performance comes from the interference rejection resulting from the intermittent packets transmissions introduced by the IPT, which solves the hidden terminals problems and greatly enhances relay performance. Figures 13-15 compare the proposed Dot11n

(MIMO)-DCH-IPT wireless backhaul with the currently used Dot11a (SISO)-SCH-Conv one using the 48Mbps PHY layer. About 40 % improvements are obtained in the throughput and Average delay using the proposed Dot11n-DCH-IPT backhaul. Also, very large improvement occurred in packet dropping rate results from using the high inference tolerances Dot11n and DCH-IPT schemes. These results verify the effectiveness of the Dot11n-DCH-IPT based wireless backhaul as a key enabler for the next wireless mobile communication generation.

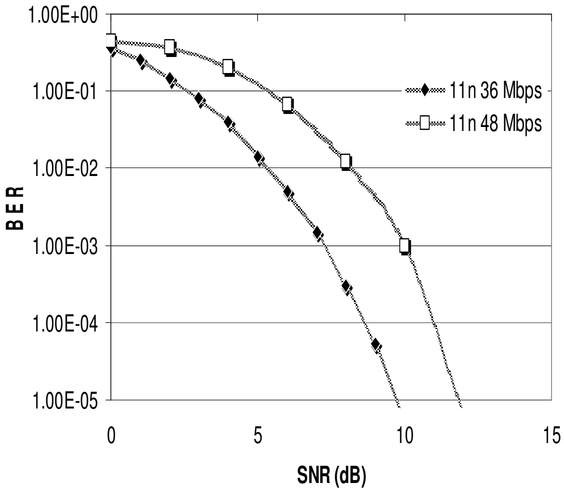


FIGURE 9: BER performances of Dot11n 36 and 48 Mbps.

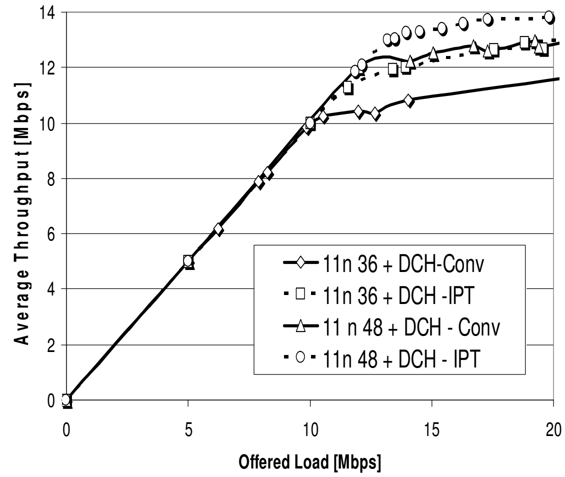
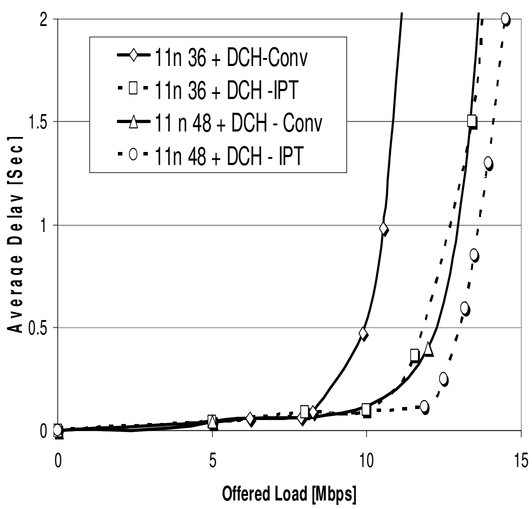


FIGURE 10: Aggregated end-to-end



FIGUER 11: Average Delay.

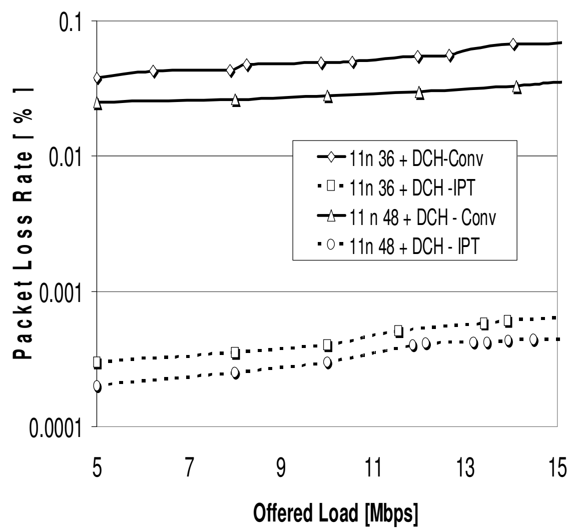


FIGURE 12: Packet Loss Rate.

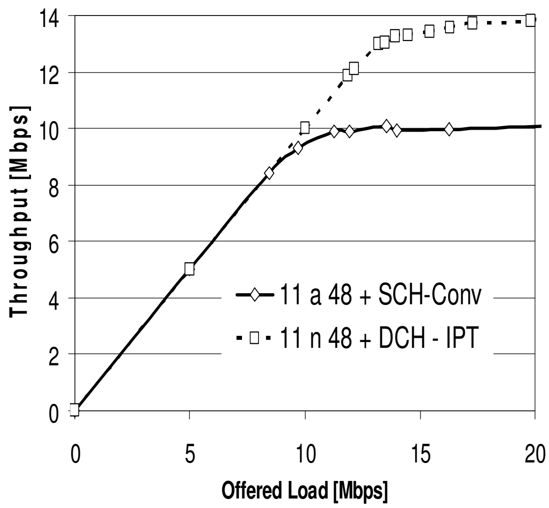
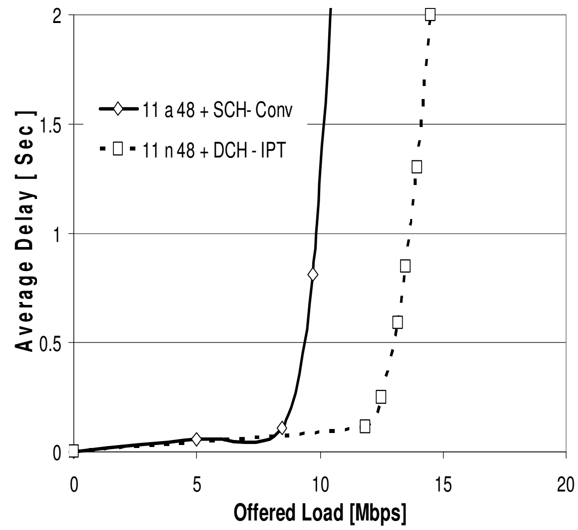


FIGURE 13: Aggregated end-to-end throughput.



FIGUER 14: Average Delay.

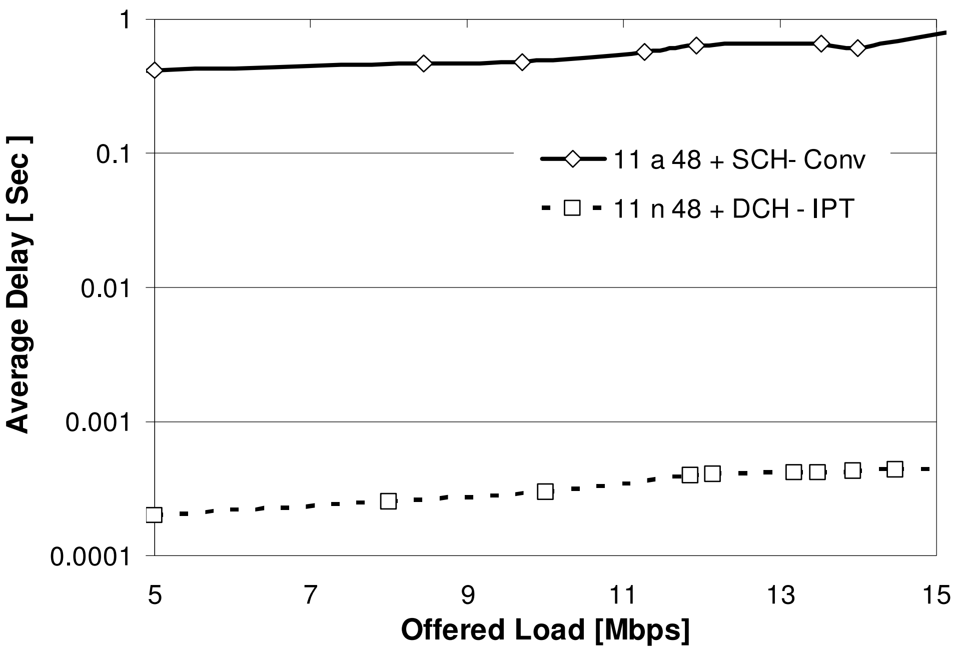


FIGURE 15: Packet Loss Rate.

1. CONSLUSION & FUTURE WORK

The IEEE 802.11n MIMO-OFDM standard is a promising technique for the next generation wireless backhaul networks. The application of this standard as a wireless interface in these networks needs an efficient relaying protocol to exploit its high speed capabilities. We showed that Dual Channel (DCH) relaying protocol is an efficient relaying protocol suitable for Dot11n-based backhaul, and we proved that the achieved throughput improvement of Dot11n-DCH is more than those achieved by Dot11a-DCH with conventional method of relaying. In addition, and in order to further improve this Dot11n based wireless backhaul, we adopt the IPT forwarding protocol to be compatible with the Dot11n standard by introducing DCH-IPT. We proved the effectiveness of the Dot11n-DCH-IPT based backhaul over the Dot11n-DCH-Conv based one, and over the currently used Dot11a-SCH-Conv one.

For further investigations, we will try to optimize the spectral efficiency of DCH-IPT and produce an optimized relying protocol for MIMO (Dot11n) transmissions.

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