An Efficient Wireless Backhaul Utilizing MIMO Transmission and IPT Forwarding

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Abstract

Wireless backhaul has been 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 performance network, high throughput, low average delay and low packet loss rate, is highly appreciated to sustain the increasing proliferation in multimedia transmissions. The critical issue reducing the performance of wireless backhaul is the interference occurred in the network due to simultaneous nodes transmissions. In this research, we propose a high performance wireless backhaul using the low interference sensitivity MIMO based nodes. MIMO transmission has a better BER performance over SISO one even with the same transmission rate and bandwidth, which means that MIMO can operate at lower SINR values than SISO and give the same performance. This MIMO robust performance against interference gives us a greater benefit when adopted as a wireless interface in wireless backhaul than SISO. These facts motivated us to use the IEEE 802.11n the current MIMO standard to design a MIMO based wireless backhaul. In addition and to justify our assumptions, we investigate the effect of MIMO channels correlation, a major drawback in MIMO transmission, upon the system performance, and prove the robustness of the scheme under different MIMO channels correlation values.

After proving the effectiveness of MIMO as a wireless interface for wireless backhaul, we further improve the performance of this MIMO-backhaul using the high efficient Intermittent Periodic Transmit (IPT) forwarding protocol. IPT is a reduced interference packet forwarding protocol with a more efficient relay performance than conventional method in which packets are transmitted continuously form the source nodes. By using these two techniques (IEEE 802.11n (MIMO) + 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 simply applying IEEE 802.11n to conventionally relayed backhaul.

The proposed wireless backhaul will accelerate introduction of picocell based mobile communication systems.

Keywords: Wireless Backhaul Networks, IEEE 802.11n, 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 been 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) with PHY and MAC enhancements [8]. Using different space time code structures, the Dot11n's MIMO-OFDM PHY layer can support data ranges up to 600 Mbps which is higher than IEEE 802.11a/g (Dot11a/g) data rate (54 Mbps at maximum). In order to take the full advantage of Dot11n PHY layer enhancements, TGn also enhances the MAC layer by introducing new frame structures that can be used to aggregate multiple subframes to improve throughput.

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 IEEE 802.11s performance, an IEEE 802.11 standard for Wireless Mesh Networks (WMN), by using Dot11n [5]. To do that, the authors in [5] first utilize the variable transmission rate of Dot11n to find the best PHY data rate related to instantaneous channel quality. 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 knowledge of the authors, most of the studies that adopt Dot11n utilize its MAC and PHY enhancements to improve the performance of Wireless Mesh Networks (WMN) and Ad-Hoc networks, whereas no 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 adopt a 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. 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 node positions. Difference of the two routings is shown in Fig. 1.

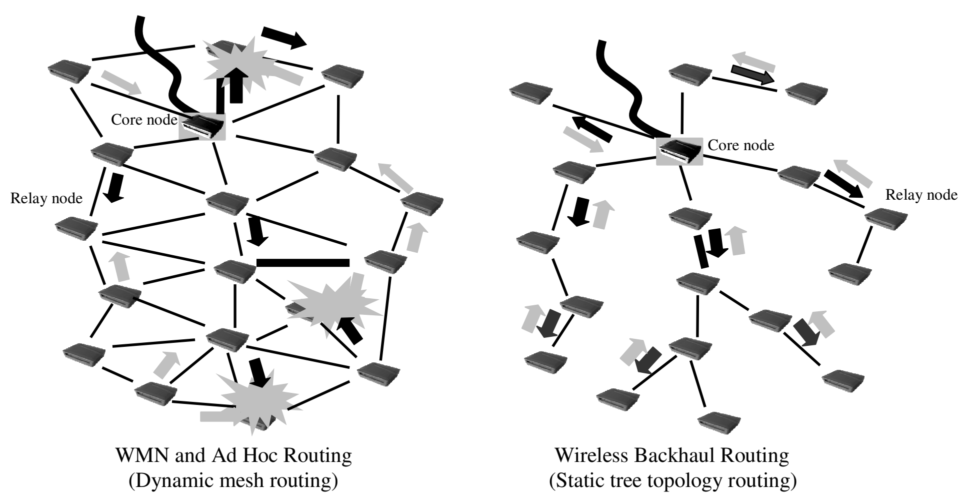

Figure 1: WMN and Ad Hoc Routings versus Wireless Backhaul Routing

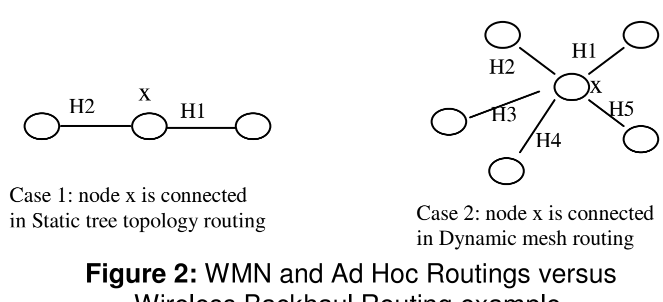

Figure 2: WMN and Ad Hoc Routings versus Wireless Backhaul Routing example.

In wireless backhaul with a static tree topology routing, since we can reduce the number of intersections on its routes as shown 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. To deeply understand this point, consider the two cases in Fig. 2. In case 1, node x has only two intersection connections, and in case 2 node x has many intersection connections (5 connections in this example). Let us suppose immobile scenario which is the static tree topology case for both cases, so in case 1, it is required from node x to make only two MIMO channel matrices estimation (H1 and H2) procedures and only two MIMO synchronization procedures and save these data (channels estimation and synchronization) for other MIMO detections which saves time and computation , but in case 2, it is required from node x to make five (for this example) channel matrices estimation and synchronization procedures and save these data for other detection procedures. In addition, and if we assume mobile scenario which can only happen for case 2 (the WMN and Ad Hoc routing topology case), then node x will always need to make MIMO channel matrices estimation and synchronization for every transmission which extremely increases the complexity and time delay required to detect MIMO signal. So we can conclude that; the static tree topology routing has a lower complexity and time delay than the dynamic mesh one when adapted to MIMO transmissions. This will deliver us a larger benefit of MIMO adoption to wireless backhaul compared with other wireless multihop networks.

This paper considers an application of Dot11n as a MIMO wireless interface to wireless backhaul with a static tree topology routing in order to enhance throughput and spectrum efficiency of its relay network. To cope with this issue, we first adopt Dot11n for conventionally relayed wireless backhaul in which packets are transmitted continuously from source nodes, and compare its performance with the currently used Dot11a (SISO) under the same conditions of evaluation (transmission rate, bandwidth, evaluation site….,etc). Although we compare the two performances using the same conditions of evaluations, Dot11n (MIMO)-backhaul show a significantly improved performance, this is because MIMO based relay nodes have a lower interference sensitivity (a vital demand for high performance wireless backhaul) than SISO based ones. This MIMO's low interference sensitivity comes from MIMO's much better BER (Bit Error Rate) characteristics compared to SISO, which gets MIMO operates under lower SINR (Signal to Interference Ratio) conditions. This MIMO low interference sensitivity gives us a higher performance backhaul over SISO based one.

One of the major drawbacks degrading the BER performance of Dot11n and MIMO transmission in general is MIMO channels correlation. MIMO transmission has an optimal BER performance under completely uncorrelated MIMO channels, and this performance is degraded as the correlation increased. In order to investigate the effect of MIMO channels correlation on system performance, we test the performance of the proposed Dot11n-conventional backhaul under different channels correlation coefficient values. We show the robustness of the scheme under different channels correlations, which further supports the idea of adopting Dot11n (MIMO in general) as a cost effective way in realizing a high performance wireless backhaul.

After proving the effectiveness of Dot11n as a wireless interface for wireless backhaul, we further improve the relay efficiency of this Dot11n based network through the utilization of Intermittent Periodic Transmit forwarding protocol (IPT) [9]. IPT is a provably efficient relaying protocol in which, a source node sends source packets intermittently and periodically with a controllable transmit period. By suitably adjust this period, we can eliminate packet interference occurred in conventional method and maximize the relay efficiency [10]. Obtained results show the effectiveness of IPT based Dot11n wireless backhaul over conventionally based one.

The rest of the paper is organized as follows. Section 2 describes IPT protocol in more details. The simulation scenarios and performance metrics are given in section 3. Section 4 gives a comparison between Dot11a and Dot11n conventionally based backhauls. Section 5 shows the Impact of MIMO channel correlations upon system performance. Further performance improvements using the advanced packet forwarding technique (IPT forwarding) is given in section 6 followed by the conclusion in section 7.

2. Intermittent Periodic Transmit (IPT) Forwarding Protocol

Intermittent periodic transmit (IPT) forwarding is a highly efficient packet relay method for wireless multihop networks in general and backhaul in especial [9] [10]. In this method, a source node intermittently sends source packets with some transmit period, and intermediate nodes forward each incoming packet immediately after the reception of it. Figure 3 shows packet relays carried out by IPT in which two transmit periods, P_1 and P_2 are given. If the transmit period is greater than a certain threshold (critical limit), packet collisions due to interference are removed, hence collision free wireless multihop relay is realized. Ascertaining the reception states at the intermediate and destination nodes in Fig.3, throughput measured by the respective nodes is constant irrespective of hop counts which completely changed the old thought: the throughput is decreased as the hop nodes numbers is increased [11]. An adaptive transmit period adjustment protocol has been proposed in [10] in order to optimally eliminate the interference and maximize the throughput.

After proving the efficiency of IPT over the conventional method of relaying in which packets are transmitted continuously with minimum path loss routing, The authors proposes a new routing method, called spiral mesh routing, to enable the IPT in 2-dimentional base nodes layout. With the spiral mesh routing, neighboring nodes are linked together in a point to point fashion so as to make a spiral-shaped route and multiple spiral routes are folded assigning each of them a different channel. This technique removes intersections on respective routes and reduces interference in the direction toward or apart from the central node, which enables the IPT for 2D.
Further developing researches are conducted to increase the efficiency of IPT forwarding for different scenarios and prove its efficiency over the conventional method of relaying [12] [13].
In this paper, we will only use the basic idea of IPT as shown in fig.3.

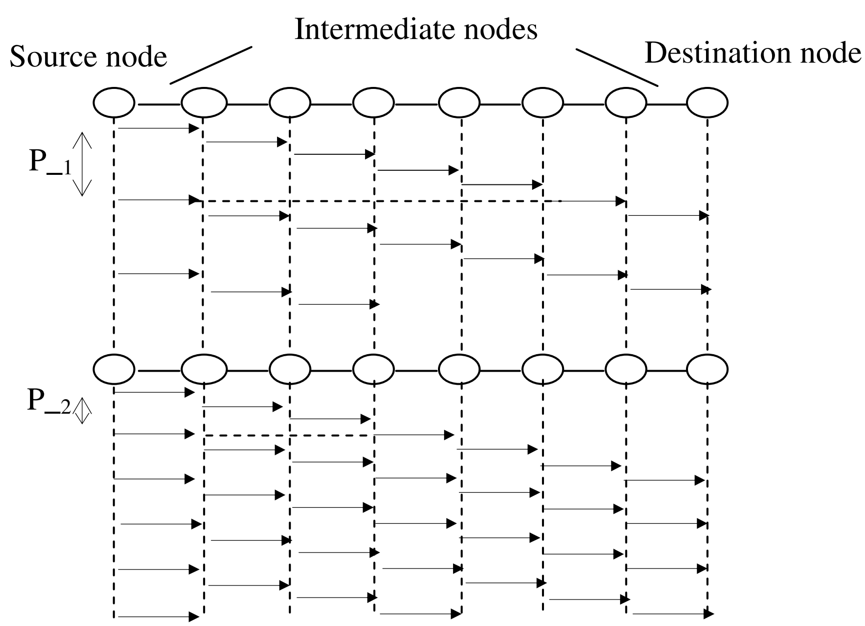

Figure 3: Packet relays by the IPT forwarding

3. Simulation Scenarios and Performance Metrics

To evaluate the performance of the suggested MIMO wireless backhaul network and prove its efficiency, we link the MATLAB program with our original network simulator. The MATLAB program is used to evaluate the PHY layer performance, and the network simulator is used to evaluate the whole system performance using the PHY performance data obtained by MATLAB.

3.1 Simulation Scenarios and Parameters

3.1.1 PHY Layer

In order to prove the efficiency of MIMO wireless backhaul over SISO based one, we compare the performance of two PHY layers

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

For fair comparison, the evaluation was done under the same conditions, .i.e. transmission bandwidth, transmission rates….etc,
We evaluate Dot11n and Dot11a PHY performances under two transmission rates 36Mbps and 48Mbps.

Table 1 shows Dot11n and Dot11a PHY layers simulation parameters:

Parameter	Dot11n	Dot11a
Bandwidth	20 MHz	20 MHz
Number of Data Subcarrier	48	48
IFFT Size	64	64
Cyclic Prefix length	16	16
Pilot Subcarriers per Symbol	4	4
QAM mapping	QPSK-16QAM	16-64 QAM
Transmiter antennas	2	1
Receiver antennas	2	1
FEC Rate	¾, 1/2	¾, 2/3
Raw Data Rates	36, 48 Mbps	36, 48 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 Tmax(MAX delay spread)=300ns, Trms (RMS delay spread)=150ns		

TABLE 1: PHY layers parameters

3.1.2 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.

3.1.3 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 origination 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 [14].

3.1.4 Packet forwarding methods

In order to prove the efficiency of MIMO- IPT wireless backhaul over MIMO – conventional based one, we compare the two-method with the same forwarding path shown in Fig 4.

- **Conventional method**- packets are transmitted continuously with minimum path loss with RTS/CTS MAC mode for all transport sessions.

- **IPT protocol**- IPT protocol is used with basic MAC mode.

3.1.5 Evaluation Site

We chose the floor of our department building as a test site Fig 4. 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 [15], 12 dB penetration loss of the wall [16]. 23 base nodes are placed on the floor and a core node is placed on stairs area of the floor Fig 4. A forwarding path is formed in advance and fixed during simulation Fig 4. 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.

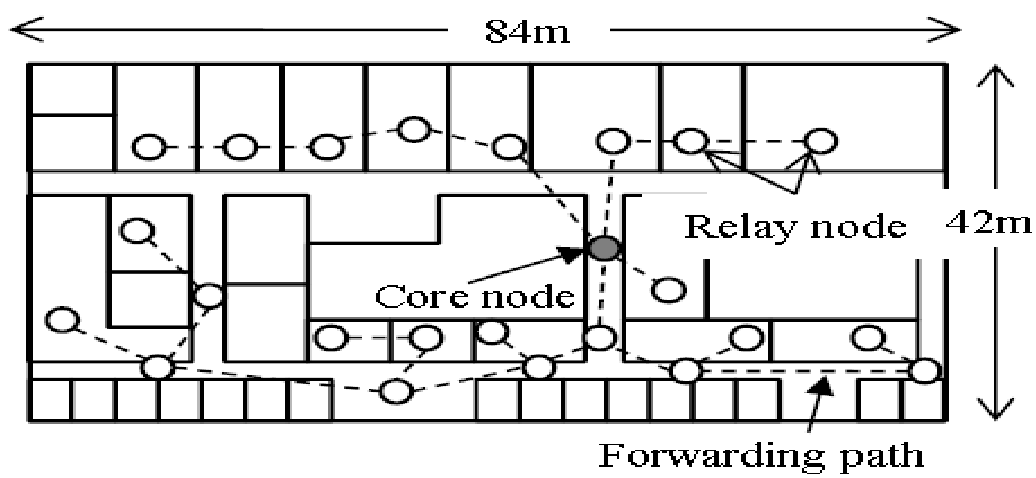

Figure 4: Floor plan and node layout for evaluations

3.2 Performance Metrics

3.2.1 PHY layer simulator

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

3.2.2 System level simulator

Three system level 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.

4. Comparison between Dot11a and Uncorrelated Channels Dot11n based Backhauls

Mont carol simulations are carried out for evaluating the comparison between Dot11a and Dot11n based wireless backhauls.

4.1 PHY Layer Simulator

Figure 5 shows the BER performance of the compared PHY layers (Dot11a 36, 48 Mbps and Dot11n 36, 48 Mbps). Although we compare the same transmission rates for both PHY layers, Dot11n shows better BER performance than Dot11a. This Dot11n better BER performance comes from using multiple antennas at both transmitter and receiver (MIMO) which is not the case for Dot11a. 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 2*2 MIMO Dot11n uses QPSK with FEC=3/4. This Dot11n's MCS reduction resulting from using MIMO greatly enhances its BER performance.

4.2 System Level Simulator

Using the BER performances of Dot11a and the uncorrelated channels Dot11n evaluated in section 4.1, we compare their system level performances using conventional method of relaying. Figures 6-8 show the system level performances of Dot11a and Dot11n, these figures show the highly efficient Dot11n performance compared with Dot11a under the same transmission rates. This Dot11n high performance comes from its better BER performance as explained in section 4.1. Better BER performance means that for a certain required PER (Packet Error Rate) performance value, MIMO operates at a lower SINR (Signal to Interference Ratio) value than SISO, which gives MIMO robust characteristics against interference, i.e., MIMO has a lower sensitivity to interference than SISO. This important MIMO phenomenon has a great impact on system performance in which interference causes a significant degradation in performance. These facts are reflected on the system level performance in terms of higher throughput, lower delay and lower packet loss rate of Dot11n based backhaul than those achieved by Dot11a based one as revealed by figures. These simulations provide evidence the idea of enhancing wireless backhaul performance using MIMO-based nodes.

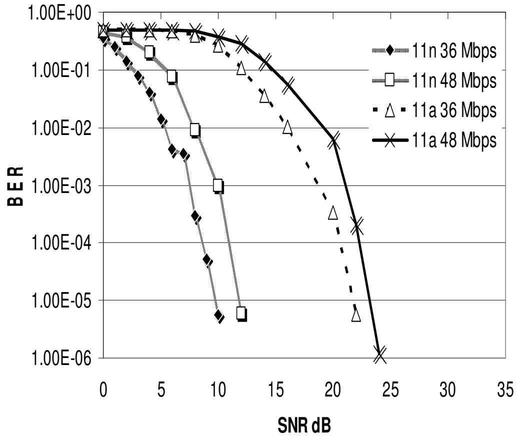

Figure 5: BER performance of Dot11n and Dot11a

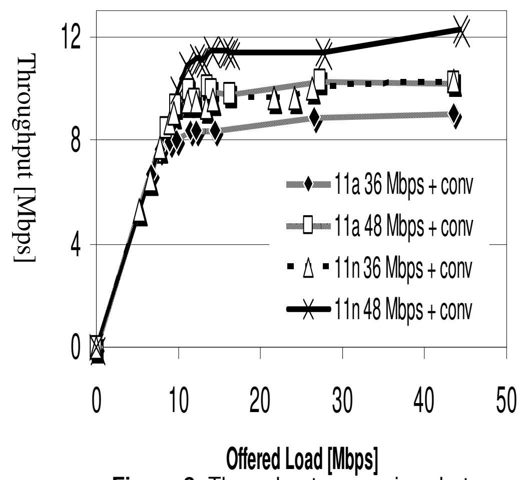

Figure 6: Throughput comparison between Dot11a and Dot11n with conventional method

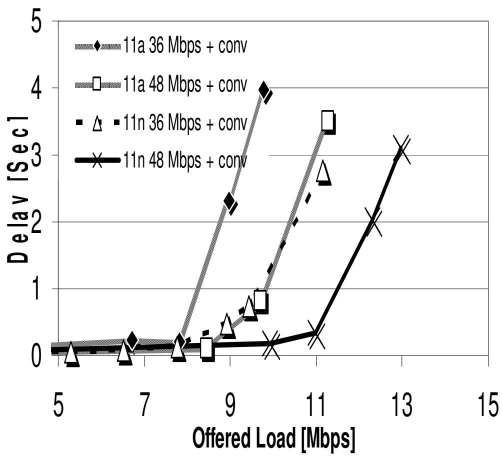

Figure 7: Delay comparison between Dot11a and Dot11n with conventional method

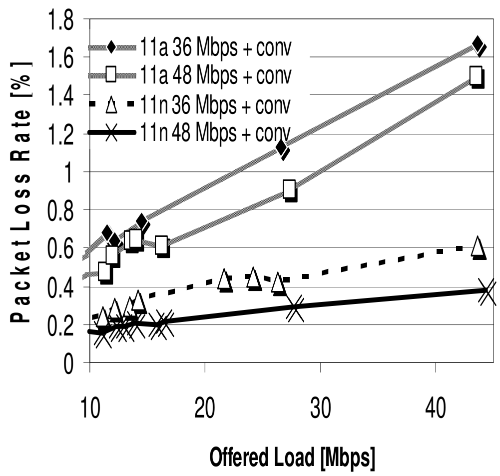

Figure 8: Packet Loss Rate comparison between Dot11a and Dot11n with conventional method

5. The Impact of MIMO Channels Correlation upon System Performance

Mont carol simulations are carried out for evaluating the effect of MIMO channels correlation upon the system performance.

5.1 PHY Layer Simulator

In this simulation, we evaluate Dot11n 48Mbps performance under different MIMO channels correlation coefficient values 0, 0.5, and 0.75; figure 9 shows the resulting BER performance. From this figure, we can conclude that; as the MIMO channels correlation increased the BER performance degraded, and the optimum BER performance is obtained when the MIMO channels are uncorrelated (Corrcof = 0). Although of Dot11n BER degradation due MIMO channels correlation, it still shows a better BER performance than Dot11a even with a high correlation value of 0.75.

5.2 System Level Simulator

Using the BER performances of Dot11n 48 Mbps under different MIMO channels correlation coefficient values (0, 0.5, and 0.75) evaluated in section 5.1, we measure the system level performance using these values with conventional method of relaying. Figures 10-12 show the system performance under each correlation value. From these figures, we can observe the neglected effect of channels correlation on throughput and delay performances, but the packet loss rate performance is little bit affected by this correlation, this is because packet loss rate is highly sensitive to PHY BER performance. Theses neglected effects come from the little changed Dot11n's BER due to channels correlation. All these results show the robustness of Dot11n and MIMO in general as a wireless backhaul interface even in a highly correlated MIMO channels.

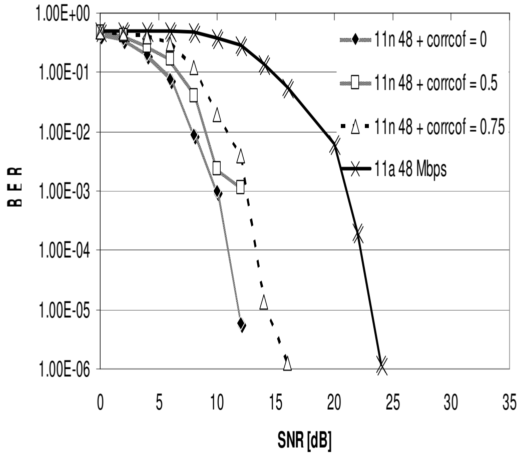

Figure 9: BER performance of correlated channels
Dot11n 48 Mbps.

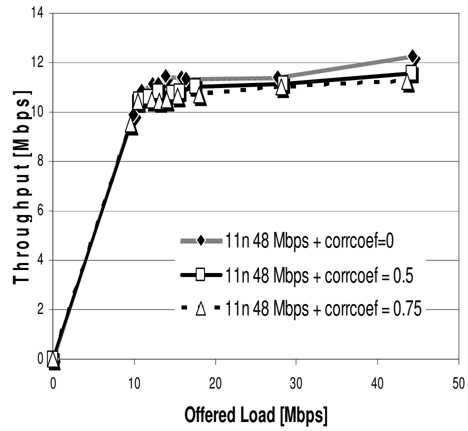

Figure 10: Throughput performance of Dot11n 48 Mbps+ conventional method for different MIMO channels correlation

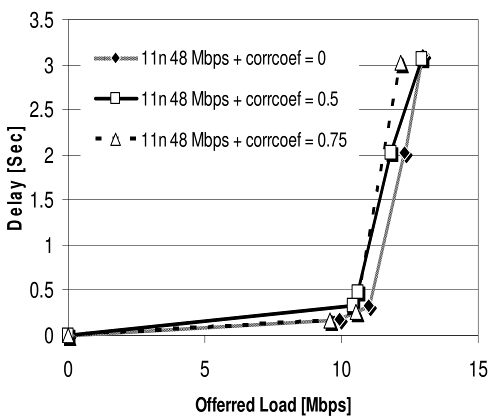

Figure 11: Delay performance of Dot11n 48 Mbps + conventional method
for different MIMO channels correlation

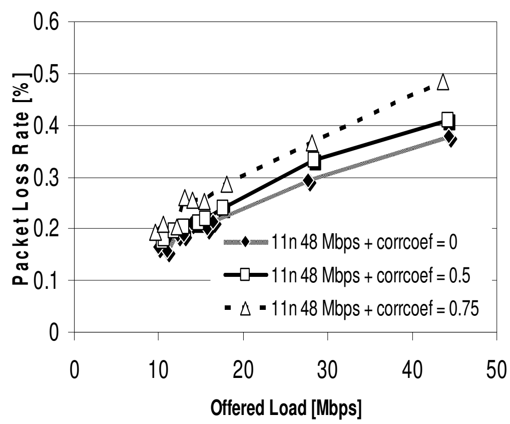

Figure 12: Packet Loss Rate performance of Dot11n 48 Mbps + conventional method
for different MIMO channels correlation

6. Further Performance Improvements using Advanced Packet Forwarding Technique (IPT forwarding)

In this section, we introduce the Intermittent Periodic Transmit (IPT) forwarding protocol as an advanced packet forwarding technique, previously proposed by the authors [9], to enhance the relay efficiency of the suggested MIMO – wireless backhaul instead of the conventional method of relaying.

6.1 IPT Based Wireless Backhaul Performance

Mont carol simulations are carried out for evaluating the system performance using IPT forwarding

6.1.1 Dot11a versus Dot11n in IPT Environment

By using the BER performance of Dot11a and uncorrelated channels Dot11n evaluated in section 4.1, we compare Dot11a and Dot11n system performance using IPT protocol, figures 13-15 show system throughput, average delay, and packet loss rate in IPT environment. Also, in these simulations, Dot11n shows a much better performance than Dot11a from the system point of view.

6.1.2 Comparison between Dot11n-IPT and Dot11n-Conventional Backhauls

In these simulations, we compare the system level performance of Dot11n 48 Mbps IPT based and Dot11n 48 Mbps conventionally based backhauls. Figures 16-18 show the system level performances of these two backhauls. Simulation results ensure better performance of the IPT based network over conventionally based one. This enhanced IPT performance comes from the interference rejection resulting from the intermittent packet transmission introduced by IPT. These results verify the effectiveness of the MIMO-IPT based wireless backhaul as a key enabler for the next wireless mobile communication generation.

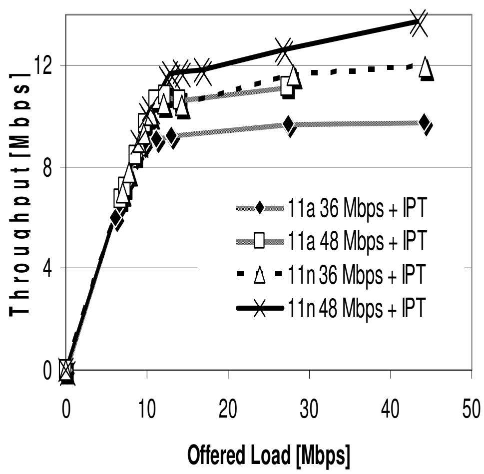

Figure 13: Throughput comparison between Dot11a and Dot11n with IPT

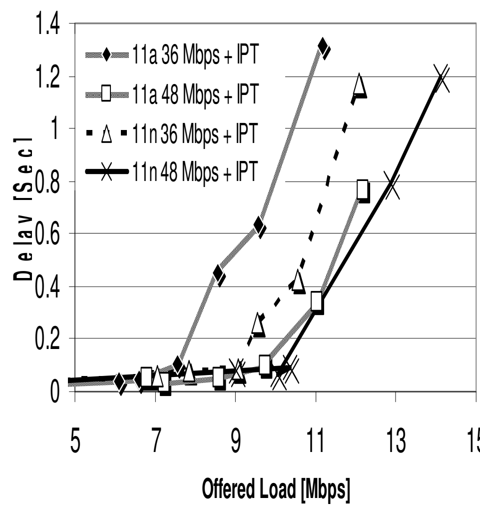

Figure 14: Delay comparison between Dot11a and Dot11n with IPT

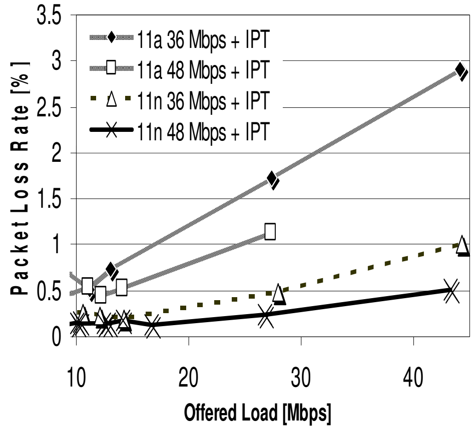

Figure 15: Packet Loss Rate comparison between Dot11a and Dot11n with IPT

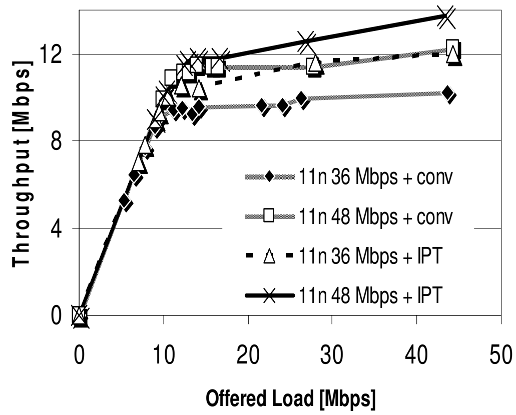

Figure 16: Throughput comparison between conventional method and IPT with Dot11n

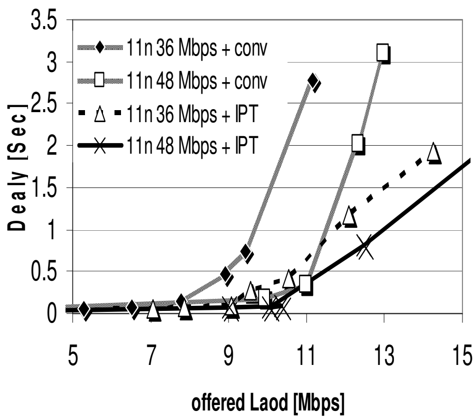

Figure 17: Delay comparison between conventional method and IPT with Dot11n

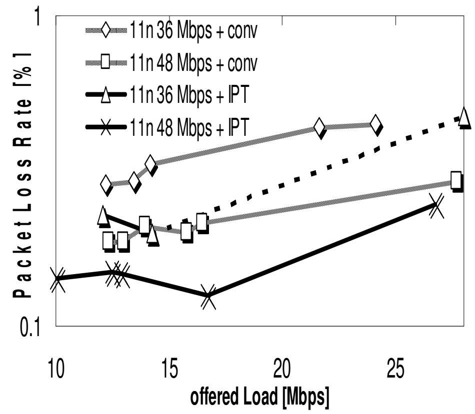

Figure 18: Packet Loss Rate comparison between conventional method and IPT with Dot11n

7. CONSLUSION & FUTURE WORK

In this paper, we investigate the application of Dot11n (MIMO standard) as a low interference sensitivity wireless interface, with a good BER performance, to improve the performance of the current Dot11a (SISO) based wireless backhaul networks. We show the effectiveness of applying MIMO in terms of backhaul system performance. MIMO based wireless backhaul has a higher throughput, lower average delay, and lower packet loss rate than SISO based one. In addition, we study the effect of MIMO channels correlation on the proposed wireless backhaul performance, and we prove the robustness of the scheme against different correlation values.

At the end of this research, we consider the application of Intermittent Transmit Periodic (IPT) forwarding as a packet forwarding protocol in order to improve the relay efficiency of the MIMO based wireless backhaul. MIMO–IPT wireless backhaul outperforms the MIMO-conventional based one, which provides evidence the application of MIMO-IPT wireless backhaul as a key enabler for the next wireless backhaul generation.

For future work, we will modify the IPT protocol, like multi-channel IPT, to be more suitable for MIMO transmissions and obtain a further improved wireless backhaul.

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