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Analysis of IEEE802.11n Dual Radio Relay Network Topologies

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Abstract. This paper presents a performance analysis of several representative dual-radio relay network (DRRN) topologies. In our architecture, both access and backhaul links are constructed using IEEE802.11n radio interfaces operating in 2.4GHz band. We first investigate the effects of multihop and star relay configurations on aggregated client throughput performance. Then we study how Received Signal Strength Indicator (RSSI) or received signal power may impact on DRRN's network coverage and capacity performance. The insights gained from this study will provide a good reference for on how to design and deploy DRRN.

Keywords: Wireless Multihop, Relay, Coverage and Capacity, Performance Analysis

1. Introduction

IEEE802.11 WLAN technologies have been enj[1]oying enormous growth since its inception. Beginning with IEEE802.11b standard which merely offers 11Mbps, the recently ratified IEEE802.11n [1] is now providing physical data rates up to 600Mbit/s using Multiple Input Multiple Output (MIMO) antenna spatial multiplexing technique. In the near future, capacity of up to 1Gbps and 7Gbps will be made possible by 802.11ac and 802.11ad technologies respectively. The continuous and rapid evolutions of these WLAN technologies not only make more bandwidth demanding applications possible, it also alters our prior understanding on dependent technologies such as wireless relay, multihop and mesh networks. For wireless relay/multihop/mesh networks, the most commonly known practice adopts dual radio architecture i.e. IEEE802.11a radios at the backhaul and IEEE802.11g for the access. In addition to the benefit of separating the frequencies between backhaul and access tier, IEEE802.11a also has more non overlapping channels and much less congested spectrum band. With 802.11n, the same frequency separation and number of orthogonal channels can be attained.

At present even though there are a wide range of 11n-based wireless mesh/multihop network products and solutions in the market, the performance of such system is not well understood especially from the capacity and range (coverage) point of view. Our earlier work [2] provides some insights on basic coverage and capacity analysis for 802.11n multiradio multihop network with more than 2 radio interfaces. Though promising, there are various impeding challenges on commercializing such multiradio systems which include hardware resource limitation, additional protocol support for multiple radio interfaces, simultaneous transmissions over collocated 802.11n radios and so on. On the other hand, dual radio systems are much more "deployment friendly" besides having advantage in cost. Due to that many household wireless mesh/multihop products from Tropos, Firetide, etc, are still based on dual radio configuration. In fact many of these so called "multiradio" products are actually dual radio systems. With this motivation, we see the need to perform a more detailed study on capacity and coverage performance of the Dual-Radio Relay Network (DRRN) using 802.11n interfaces.

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In this work we have scoped down our study to only focus only several representative topologies. We have also added a number of practical constraints in our analysis to give some insights on how DRRN network might perform in typical deployment scenarios.

The reminder of this paper is organized as follows. Next section discusses the dual-radio relay architecture and possible topologies which can be derived from this architecture. Section 3 presents the system model and assumptions. Results are discussed in section 4 and finally the conclusions are drawn in section 5.

2. Architecture and Topology

The architecture in Fig. 1 consists of Dual-Radio Relay (DRR) nodes that are interconnected in multihop fashion to form a Dual-Radio Multihop Relay network (DRMR).

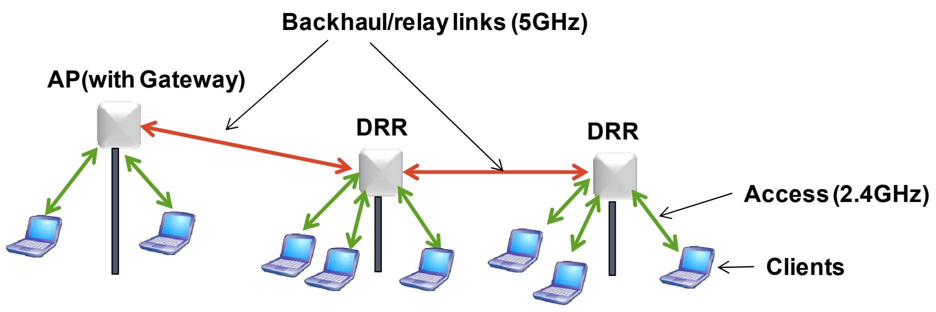


Fig. 1: Dual Radio Relay Network (DRRN) Architecture

In this paper, both the access and backhaul tiers are using the same 2.4GHz band. From this basic architecture, different topologies can be derived as shown in Fig. 2.

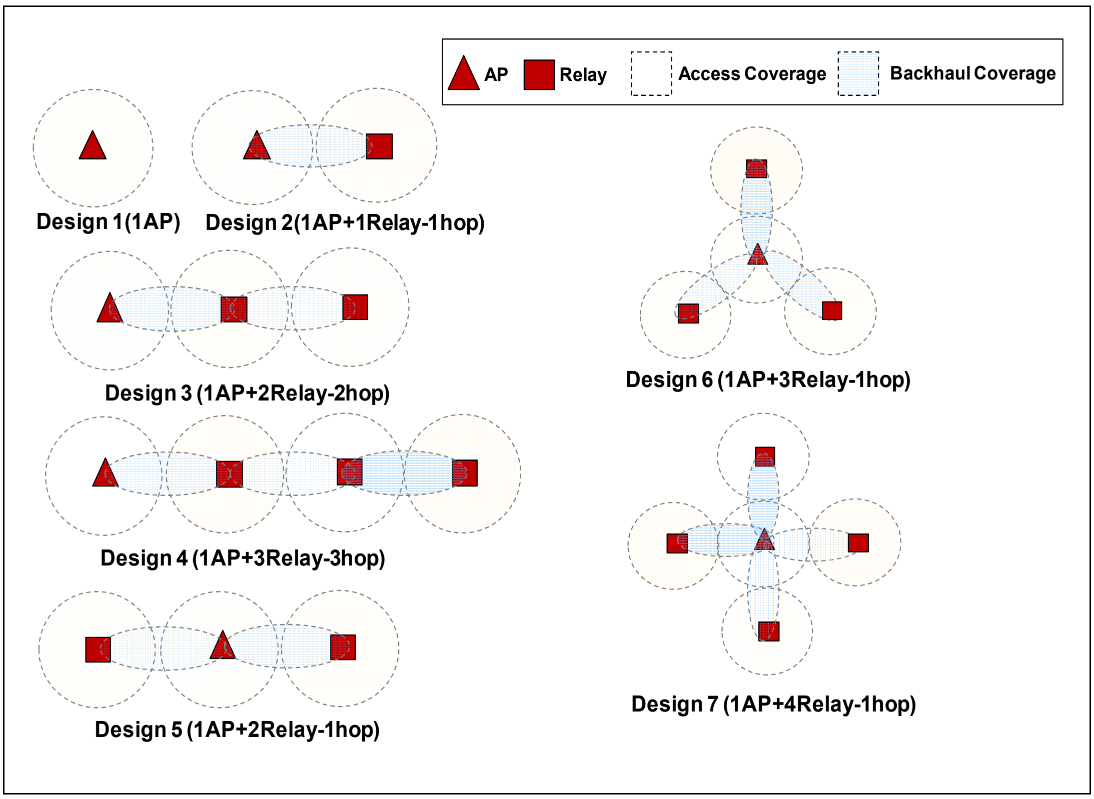


Fig. 2: Possible topologies with different number of DRR

There are essentially two broad categories of relay topology namely 1) Multihop or Chain and 2) Star. In the chain topology DRR nodes further hops away need to hop on to DRR nodes nearer to the AP (with gateway) to access to the core network and hence the Internet. For star configuration in contrary, only 1 hop is require to reach the AP with gateway. Although bigger topologies with more nodes or hop count can be derived, the 7 topology designs illustrated are believed to be sufficient to provide some general insights.

3. System Model and Assumptions

3.1. Link Budget Model

For the coverage or range study we adopt free space path loss (FSPL) model:

$$PL_{propagation} = 10\alpha(\log_{10}(d)+3)+20\log_{10}(f)-147 \quad (1)$$

Where α is the propagation coefficient, d is the distance in kilometer and f is the carrier frequency in Hertz. The general link budget is given as:

$$PL_{\max} = EIRP - R_{sen} + G_{rx} - FM \quad (2)$$

Where PL_{max} is link budget in dB, EIRP is the effective isotropic radiated power, R_{sen} is the receiver sensitivity, G_{rx} is the receiver antenna gain and FM is fade margin in dB. Table I. highlights a general relationship between the amount of available link margin and link availability as a percentage of time according to Raleigh fading model. A good rule-of-thumb is to maintain 20dB to 30dB of fade margin at all times [3]. The rest of the parameters in the link budget model will be discussed in section 4.

Table I: Time availablity vs Fade Margin [3]

Time Availablity (%)	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

3.2. Effective Coverage

For this study we only take into consideration effective coverage area, which is represented by grey shaded circles in Fig. 3. This is valid if D ≥ 2*R which is typically the case since high gain directional antennas are used to construct the relay backhaul link in our system.

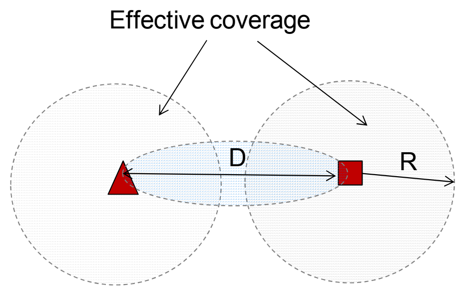


Fig. 3: Calculation of Effective Coverage

Based on the assumption above, the coverage area per cell can then be represented by:

$$A_{total} = N\Pi R^2 \quad (3)$$

Where N = number of AP or DRR, and since D = 2*R, for a selected topology:

$$A_{total} = \Pi\left(N_{ap}R_{ap}^2 + N_{relay}R_{relay}^2\right) \quad (4)$$

3.3. Capacity sharing between clients in AP and Relay

WLAN systems operate in contention mode by default as dictated by Distributed Coordination Function (DCF) and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) medium access and contention management techniques. To enable our analysis, fair sharing of capacity is assumed between the between clients in the AP and relay. This is true as long as system is not driven into saturation model. The throughput verification in section 4.1 will confirm this assumption.

3.4. IEEE 802.11n Radio Interface

Table II lists down the receiver sensitive value of each Modulation and Coding Scheme (MCS) and number of MIMO spatial streams taken from a typical IEEE802.11n product datasheet. The transmit power (TxPower) of respective MCS type is also provided.

TABLE II. Typical IEEE802.11n MCS, Receiver Sensitivity, Spatial Stream and Transmit Power (2.4GHz, 20MHz)

MCS Type	MCS Index	No. of Spatial Streams	Receiver Sensitivity (dBm)	Physical Data Rate (Mbps)	TxPower (dBm)
BPSK ½	0	1	-93	7.2	20.50
QPSK ½	1	1	-90	14.4	20.50
QPSK ¾	2	1	-88	21.7	20.50
16-QAM ½	3	1	-85	28.9	20.50
16-QAM ¾	4	1	-80	43.3	20.50
64-QAM 2/3	5	1	-78	57.8	18.50
64-QAM ¾	6	1	-75	65.0	17.50
64-QAM 5/6	7	1	-75	72.2	16.50
BPSK ½	8	2	-93	14.4	20.50
QPSK ½	9	2	-90	28.9	20.50
QPSK ¾	10	2	-88	43.3	20.50
16-QAM ½	11	2	-83	57.8	20.50
16-QAM ¾	12	2	-80	86.7	20.50
64-QAM 2/3	13	2	-75	115.6	18.50
64-QAM ¾	14	2	-73	130.0	17.50
64-QAM 5/6	15	2	-71	144.4	16.50

Number of spatial stream indicates the number of parallel data streams generated using MIMO antenna using spatial multiplexing technique. Although up to 4 streams are possible according to 11n standard, only 2 streams are implemented in most products.

3.5. Simulation parameters

Simulation parameters used in subsequent experiments are summarized in Table III as follows:

TABLE III. Radio and Environmental Parameters

Parameters	Units	11n 20MHz (Access)	11n 20MHz (Relay Backhaul)
Antenna gain	dBi	4 (Omni)	8 (directional)
RF frequency	GHz	2.4	
Channel bandwidth	MHz	20	
Transmit power	dBm	Table II	
Propagation Coefficient		2.6 (rural)	2.0 (LOS)
Link layer efficiency(φ)		0.5 (MCS 0-7) 1.6x of MCS (i+8)	
Guard interval	ns	400	
Fade margin	dB	18	28
Interference Margin	dB	3	0
Gateway Backhaul	Mbps	Capped at 2Mbps or Uncapped	

Link layer efficiency represents the effective capacity the IP layer throughput with regards to physical data rate, where in most cases is approximately 50% of the raw physical data rate. However the 50% efficiency loss is only applicable for single stream case. For two streams or 2x2 antenna case, the throughput gain when compared with single stream case is around 1.6x based on the finding in [4]. *FM* for access is set as 18dBm to represent link availability of 99% according to Table I. As for relay backhaul link which needs to be more stable, a higher fade margin of 28dBm is used to represent 99.9% of link availability.

4. Results

4.1. Throughput Verification

In this section we perform throughput verification of the proposed DRMR using Qualnet 5.2 event-driven simulator. The objective is to confirm that throughput is fairly shared as long as total aggregated client throughput does not exceed the first hop link maximum throughput capacity. The main simulation parameters are summarized in Table IV as follows.

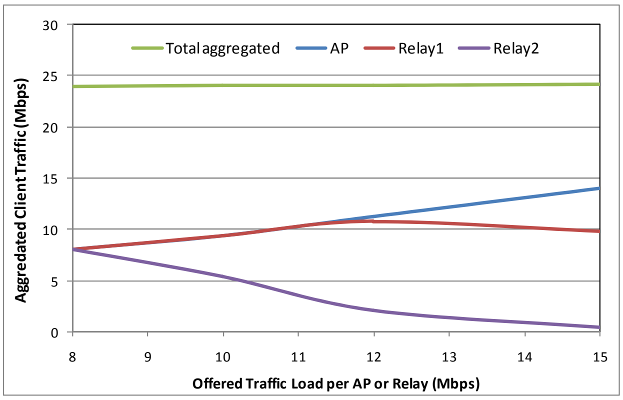
TABLE IV. Simulation Parameters (QualNet)

Parameters	**Units**	**Values**	**Remark**
Data Rate	Mbps	54	64QAM3/4, IEEE802.11ag
Short packet transmit limit	-	7	maximum number of times a short packet (CTS/ACK) will be re-transmitted
Long packet transmit limit	-	4	maximum number of times a long packet (CTS/ACK) will be re-transmitted
RTS/CTS	-	ON	Using RTS/CTS mode

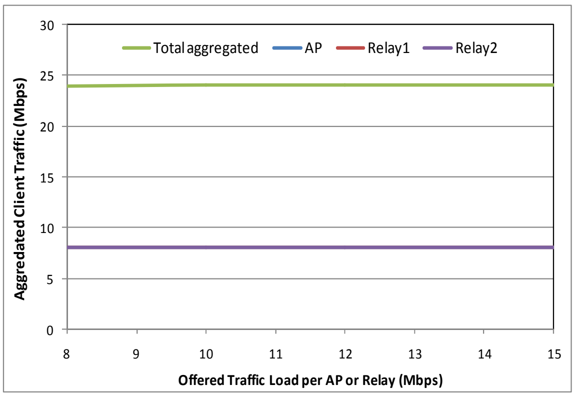
IP input queue	Byte	10,000,000	FIFO, no loss packet
Traffic type		CBR	Constant Bit Rate
Packet Size	Byte	1400	Fixed
Traffic direction		downlink	Gateway to client

*Note: other parameters which are not mentioned here are fixed according to default values specified in the standard.

In these experiments, traffics from gateway to clients in AP as well as DRR are increased gradually over time. Although 11n library is not available during the time of writing, the normalized throughput behaviour is not expected to deviate much as 11n uses the same MAC access protocol (DCF with CSMA/CA). The main intention is to investigate how the network reacts towards throughput changes under different DRMR topologies.



(a) Design 3

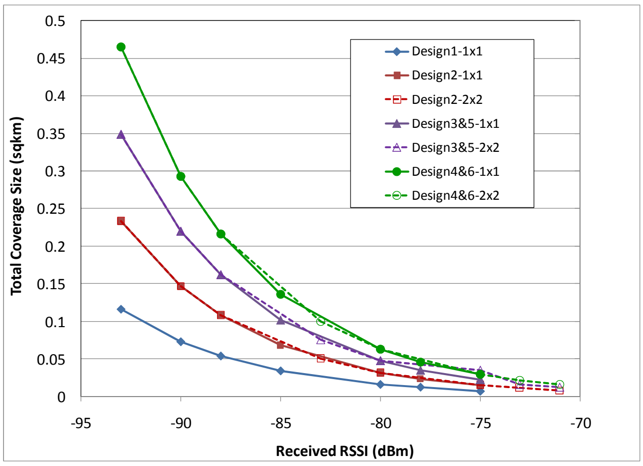


(b) Design 5

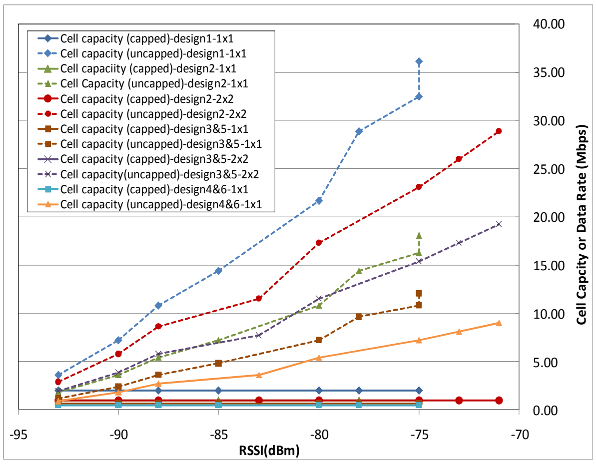
Fig. 4: Cell Throughput Analysis

Figure 4a shows that for a 3-hop DRMR configuration (design 3), fairness in client traffic (aggregated) can be ensured till 8Mbps after which the furthest relay (DRR2) will experience throughput degradation first. After the offered load is increased further, AP and relay1 "breakout point" occurs at 12Mbps. After which AP will monopolize the capacity. For a PHY data rate of = 54Mbps, the effective throughout of the first hop link is 24Mbps and when this is fairly shared by all clients at AP and DRRs, each node will have an aggregated of 24/3 = 8Mbps. It is to be reminded that since DRRs are treated as normal clients by AP the relay capacity will be compromised when the number of users in AP increases. For a 3-node star configuration, AP, DRR1 and DRR2 are shown to experience equal throughput performance. This is because all the end clients are equal hop away from the AP. From the experiment above, we can therefore conclude that throughput are fairly shared among the clients in AP and Relays as long as the total aggregated client throughput does not exceed the first hop link maximum throughput capacity for the multihop configuration (design 2, 3 and 4). For the star configuration (design 5, 6 and 7), the throughput is fairly distributed among the branches by default but only capped at the saturated load level even though the offered load increases further.

4.2. Topology Analysis



(a) Total Network Coverage



(b) Capacity per Cell

Fig. 5: Network Coverage and Cell Capacity

Figure 5a shows that larger topologies with more nodes provide bigger coverage as expected. RSSIs between -85 and -95dBm show the highest coverage size gain for all topologies. Topologies that adopt dual spatial streams (2x2 MIMO) have slightly lower coverage than its single stream (1x1) variant due to the higher requirement on RSSI level. In contrast to coverage performance, it can be observed from Figure 5b that capacity per cell increases as the RSSI level while there number of nodes decreases. Obviously the dual stream options provide higher cell capacity. Interestingly, design 2-1x1 SISO offers similar capacity as Design 3&5-2x2 MIMO in uncapped case. However if there is a 2Mbps capacity cap at gateway, MIMO does not provide any capacity advantage therefore limiting such network to merely provide coverage extension.

5. Conclusions

We have presented a capacity and coverage performance of DRRN taking into consideration a number of representative topologies that can be derived from this architecture. In the experiment we have shown that multihop and star configurations have different ways of sharing clients' load. The interesting insights gained from the coverage and capacity analyses will provide a good reference on how to design and deploy DRRN.

6. References

[1] IEEE 802.11n: Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancements for Higher Throughput, 2009.

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