Gormus, S., Kaleshi, D., McGeehan, JP., & Munro, ATD. (2006). Relaying and routing in wireless networks: a throughput comparison. In *IEEE 63rd Vehicular Technology Conference 2006 (VTC 2006-Spring), Melbourne, Australia* (Vol. 1, pp. 440 - 445). Institute of Electrical and Electronics Engineers (IEEE).
<https://doi.org/10.1109/VETECS.2006.1682853>

Peer reviewed version

Link to published version (if available):
[10.1109/VETECS.2006.1682853](https://doi.org/10.1109/VETECS.2006.1682853)

[Link to publication record in Explore Bristol Research](#)
PDF-document

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

Relaying and routing in wireless networks: a throughput comparison

Sedat Gormus, Dritan Kaleshi, Joe McGeehan, Alistair Munro

Department of Electrical and Electronic Engineering

University of Bristol, Merchant Venturers Building, Woodland Road, Bristol, BS8 1UB, UK

{Sedat.Gormus,Dritan.Kaleshi,J.P.McGeehan,Alistair.Munro}@bristol.ac.uk

Abstract—Relaying is a known method used to increase coverage in wireless communication systems. In addition to coverage increase, new relaying methods have been proposed that may increase the multi-hop wireless system capacity by taking advantage of higher data rates achievable with intermediate relaying nodes. At the same time, multi-hop wireless networks can be created, relatively simply, by running any of the proposed MANET routing protocols. Several questions can be raised: what is the best achievable network performance for a system composed of single-frequency wireless nodes able to use co-operative and non-cooperative relaying? how does the network throughput of a system using relaying nodes compare to that of a system that does not use relaying at all? This paper presents initial answers to these questions using results obtained through the simulation of single-frequency wireless ad-hoc networks using static and dynamic MANET routing, with nodes supporting several co-operative relaying schemas.

Index Terms—Relaying, co-operative relaying, routing, wireless networks, MIMO.

I. INTRODUCTION

The demand for faster wireless communication networks is being met by work largely developed in two directions: solutions that increase wireless link throughput, and solutions to form and maintain a wireless networking system. These two cannot continue to develop disjointly from each-other. Indeed, it can be shown that the overall network system performance with partial “layered” solutions, at best, has not improved linearly with the achieved improvements at the wireless link level (PHY layer). This realisation has given impetus to the increased interest in cross-layer optimisation protocol design in wireless networks, based on the argument that an overall general optimal networking solution may not be possible when considering the heterogeneity of the wireless link technology and its fast development pace.

Connectivity in multi-hop wireless networks can be achieved in two ways: using relaying or routing. In a communication system routing is *the properly designed* process to realise correct and efficient establishment and maintenance of connectivity between nodes over multi-hop links [15]. It is, by design, not limited (theoretically) by the size of the network,

and largely independent from the underlying link technology used. Relaying, on the other hand, is the set of solutions that provides for multi-hop connectivity at up to data link layer. The main usage of relaying in wireless networks has been to increase coverage, in particular in cellular networks [9]. Intelligent relaying and cross-layer optimised solutions at PHY and MAC layers can also be used to improve spectrum efficiency. Some of these solutions (“smart” relaying algorithms) use cooperative relaying schemas, and show the possibility of also getting improved capacity for these systems [2]-[6], [10]. For example, in their study in 1998 Sendonaris *et al.* [4] proposed a very simple and effective user cooperation technique to boost the uplink capacity, using spatial diversity, where two spatially separated Mobile Terminals (MTs) cooperated to transfer the data to the Base Station (BS) in order to create a better uplink (higher data rate).

Relaying using space time block coding was investigated by Laneman in [10], where he shows that cooperation improves the outage behaviour of the system compared to direct link communication, as well as drastically reducing the individual MTs power consumption. The concept is taken further by Dohler [2] with multi-stage distributed-MIMO systems, also known as Virtual Antenna Arrays (VAA). These systems correspond to spatially adjacent MTs grouped into VAAs. The source VAA relays its traffic via the relaying VAAs towards the destination VAA. This system is referred as VAA multi-stage communication system.

When one looks at a simple Decode and Forward (D&F) relaying solution, it is obvious it follows a store-and-forward principle, with the decisions made at MAC layer on a packet-per-packet basis. With routing, the network system is organised in multiple hops, where forwarding decisions are made on a packet-per-packet basis at each node; the overall performance decreases with the number of hops. So, the two solutions *seem* to have a similar objective: both try to create a logical overlay topology over wireless links. But this is where the similarity ends. What is not very clear at the moment is what will be the interaction between routing and relaying decisions, considering the different timescales and different hop horizon considered by the (existing) routing protocols, and the (future?) relaying protocols

Intuitively, due to the nonlinear characteristic of the wireless link (single hop), it is possible to extract performance benefits for the overall multi-hop system by placing intermediate nodes that operate at bit rates higher than what is possible to be supported for the direct link between the source and destination. Theoretically, a better performance can be achieved, if relay nodes (co-operative or non-cooperative) are introduced to the wireless communication system. The increase in the link throughput is mainly due to higher rates supported by the intermediate node links compared to the direct source-destination link.[13] Although there is a considerable amount of effort put into the analytical modelling of the link performance of the relaying algorithms, their impact on the overall network system performance has not been investigated thoroughly [13]; in particular the interaction of relaying and routing. Two questions arise: what is the achievable network performance of a system when it uses relaying? And how does the network service access point (N-SAP) throughput of a system using relaying compares to that of a system that does not use relaying? In this paper we present initial results from a simulation-based evaluation of the performance of different multi-hop ad-hoc single-frequency wireless networks under non-relaying scenarios (pure ad-hoc routing), with homogeneous relaying and routing scenarios, and heterogeneous (not all nodes participate in the relaying process). The performance is expressed in terms of best achievable throughput at network service access point.

This paper is organised as follows. First, a brief overview of the created simulation framework is given. The next section presents the scenarios simulated, and the performance of the networking system under these scenarios. Finally we give the conclusions we draw from these results.

II. SIMULATION FRAMEWORK

A. Framework outline

The simulation set-up (Fig. 1) consists of two separate platforms. An 802.11a-compatible physical layer simulation model was created to generate BER performance curves for a VAA system, using Decode-and-Forward relaying algorithms. The model allows for parameter configuration to ensure the sameness of scenario (in particular node placement vs. each-other) between the network model and the PHY layer model. The PHY layer simulation results are fed into a QualNet network model to get the performance metrics at MAC service access points (SAPs).

B. The PHY Layer Simulator

The first part of the platform consists of a PHY layer simulator based on the 802.11a standard [7] and can perform PHY layer simulations for SISO (Single Input Single Output) and Alamouti-based [8] D-STBC (Distributed-Space Time Block Codes) systems, for all 802.11a standard modes.

Fig. 1. Outline of the Simulation Framework.

In D-STBC systems, intermediate MTs form a Distributed VAA system. The distributed relays transmit the space time coded frame at the same time towards the source, the destination, or another VAA. A 2x1 Distributed-MIMO communication system is shown in Fig. 2. As the communication channel between the relaying MTs and the destination is a 2x1 MISO channel, it is possible to apply Alamouti coding on this channel [8]. The simulator allows for the introduction of other intermediate VAA relays between (i.e. a 3rd intermediate VAA tier), in which case we will have a MIMO-like channel.

It is assumed that the relaying MTs (the 2nd Tier VAA node above, and any other possible intermediary nodes) are spatially close together, thereby experiencing approximately the same path loss from the source MT and towards the destination MT. Also it is assumed that the relaying MTs are synchronised and the carrier frequencies of the individual MTs are exactly the same in the same frequency band. A SISO channel can be thought to be a 1x1 MIMO channel. Hence, with slight modifications, it is possible to get BER performance for SISO systems from the same simulator.

Fig. 2. A 2x1 Distributed-MIMO communication system.

We have focused on free space and office (indoor) propagation environments [11] to take into account the effect of the line-of-sight (LOS) and non-line-of-sight (NLOS) propagation environments. Channel A propagation model is used for the indoor scenario.

The simulator uses a constraint length seven convolutional encoder with Viterbi decoding as required in the 802.11a standard. [7].

C. Network Simulation Environment

QualNet [12] has been used as the network simulator. QualNet is an event based simulator that is designed to evaluate network system performance and assist with the improvement of the network protocol design through simulation, with particular strengths in wireless network modelling.

We have extensively modified the 802.11a PHY and MAC layer modules in QualNet to model D&F and D-STBC relaying mechanisms. The PHY layer simulator results are incorporated through the BER curves, with further modifications to the propagation modelling module to cater for the above mentioned propagation environments. The modifications are such as allow (a) to match the relaying scenario requirements (node placements), and (b) to ensure compatibility of the scenarios for simulations between the relaying PHY model and the network model, which are run separately.

We have used the AODV routing protocol [16] for initial dynamic routing scenarios. For scenarios where relaying is implemented, static routing tables are used so that the dynamic routing protocols do not affect the relaying performance of the network (i.e. there is no route discovery and maintenance phases). The relaying nodes are pre-determined in a configuration file, thus allowing the user to create any network topology by controlling the placement of the relay nodes.

III. SIMULATION SCENARIOS

The base scenarios are shown in Fig. 3. We define two types of nodes: routing nodes, which form the logical network grid topology, and relaying nodes, which may or may not be a routing node. When the term “inter-node (or node) distance” is used in the paper, it defines the distance between routing nodes in the grid topology (i.e. relates to the logical network system).

We are interested to look at (a) N-SAP throughput of a network grid system with relaying nodes, and (b) comparison of the network performance of relaying for a grid topology network with varying density of cooperative and non-cooperative relaying nodes (i.e. not all nodes participate in relaying). The base scenario is a grid topology network with all nodes running AODV, with no intermediate relaying nodes. Then we look at the performance of the same network topology with static routing (i.e. table-driven paths) under the same loading conditions. Then we look at the throughput of the same network grid topology with static routing and with relaying nodes, varying the distance between the nodes or the density (number) of relaying nodes. In every scenario, the relaying nodes are placed at optimum distance between routing nodes to achieve maximum possible link throughput.

For scenarios where all the intermediate nodes are chosen to be relays (Fig. 3-a), the relay distance is reduced by a constant value for each simulation run starting from a pre-defined start position. The step value depends on the channel model used (AWGN or Channel A). An explicit minimum distance is used,

described in more detail in each set of experiments below.

a) Grid topology with multi-stage cooperative relays.

b) Grid topology with randomly placed cooperative relays

c) Grid topology with randomly placed non-cooperative relays.

Fig. 3. Simulation Scenarios

In scenarios with a random number of co-operative relaying nodes (Fig. 3-b), the cooperative relaying nodes are placed very close to each other, so the interference caused by the extra node can be assumed to be negligible. This setup is chosen to maximise the achievable link throughput [13]. For non-

cooperative relaying scenarios, the relaying nodes are added randomly and placed exactly halfway between the original grid nodes, so as to attain optimum link performance (Fig. 3-c).[17]

All simulation scenarios use constant bit rate (CBR) traffic with 1800 bytes packet length (measured at N-SAP). The nodes are placed in pre-determined locations and for each location a simulation is run for 60 seconds. The packet transmission interval at the application layer is chosen to be 1800 microseconds. The node queues are assumed to be large enough that there is no packet drop. The CBR traffic generated by the application is chosen to be always greater than link throughput to ensure that there is no idle time in the wireless medium (saturation level).

B. Network with pure relaying scenarios

A 4x4 grid topology scenario has been setup to show the impact of multi-stage relaying on network throughput as shown in Fig. 3-a., for both Channel A and AWGN channel models, due to their different SNR behaviour [13]. The initial distances are chosen to be 26 and 200 meters for Channel A and the AWGN channel respectively. A set of simulations have been carried out for both channel models by reducing the initial inter-node distances by a constant value for each set of simulations. This enables us to see the performances of the proposed relaying methods for a grid network topology.

C. Network with partial relaying scenarios

To investigate the impact of the relaying nodes on the network throughput for an ad-hoc network with changing number of relays we have used a fixed 6x6 grid topology with relaying nodes randomly placed with a uniform distribution. Simulations are carried out for different numbers of relay nodes, different relaying methods, and for both channel models. The network density is controlled by the inter-node distances; this is set at 200m and 140m for AWGN channel models, and 18m and 14m for channel A.

CBR traffic is used for all simulations, and the fragmentation of the packets has been disabled. The traffic pattern used for the partial relaying scenario is exactly same as the rest of the scenarios.

IV. NETWORK PERFORMANCE OF RELAYING MECHANISMS

A. Network throughput with pure relaying

The setup for this scenario is shown in Fig. 3-a. The traffic is transmitted from source to destination over the co-operative or non-cooperative (D&F) relaying nodes. The routes in the network are static and don't change throughout the entire simulation. The simulations results are shown in Fig. 4.

For Channel A, the best performing relaying method is found to be D-STBC method, since space time block codes perform better in correlated propagation environments compared to non-cooperative D&F methods. As reported in [13], the deployment of relays (cooperative or non-cooperative) improves link throughput in correlated propagation

environments compared to direct communication. This is also why the D&F method also performs better than simple routing in Channel A propagation environments. Note also that, up to a certain node density, the relaying methods, cooperative or non-cooperative, outperform the network with dynamic routing protocol.

a) Network throughput – Pure Relaying – Channel A

b) Network throughput – Pure Relaying – AWGN channel

Fig. 4. Throughput vs. Network Density

The throughput results for AWGN channels indicate that the performance of dynamic routing protocol (AODV) suffers compared to relaying methods when the SNR is low (large inter-node distance). When the network density is very low (characterised by a low link SNR), the performance of the dynamic routing protocol is found to be worse than the performance of non-cooperative relaying. This can be explained by the need for increased number of route discoveries in order to maintain the source-destination link under the low SNR conditions. On the other hand, D&F relaying out-performs D-STBC relaying, since STBC are the worst performer in uncorrelated propagation environments. Note that when the network density is higher than a certain density the routing protocol takes advantage of fewer average hop counts and outperforms the evaluated relaying mechanisms.

The PHY model upper bound (PHY UB) in Fig. 4 is calculated following the definition in [14]. It shows that the throughput difference between the network throughput upper bound and the relaying mechanisms performance is significant.

B. Grid topology with random cooperative relays

We have simulated a 6x6 grid network topology (described in III.B). The base scenario running dynamic routing (AODV) over the 6x6 grid topology (Fig. 3-b) is compared to the same routing topology overlaid in a network with additional intermediate relaying (non-routing) nodes. We simulated the network with 5, 8, 12 and 16 randomly placed co-operative relaying nodes. The results, averaged over three simulation runs each, are given in Fig. 5.

a) Randomly placed cooperative relays for Channel A

b) Randomly placed cooperative relays for AWGN channel

Fig. 5. Grid topology with randomly placed cooperative relays

The results in Fig. 5-a indicate that the wireless network performance in Channel A environments and for large inter-node distances is considerably better for networks using co-operative relaying over networks with pure dynamic routing (AODV). For the inter-node (routing node) distance of 18m it can be seen that the throughput increases with increasing number of relays (optimally located relay density). For inter-node distances of 14m the dynamic routing protocol (AODV) performs better than the cooperative relaying, since AODV routes the traffic through fewer hops than the cooperative relaying methods. For both scenarios (18m-14m), it is clear that increasing the number of cooperative relays improves the relaying performance of the system. For 14m scenario, relaying outperforms routing when there are 16 cooperative relays deployed in the system.

For AWGN channels, again as in the previous section, there is

no advantage of using cooperative relays in wireless networks for large distances (200m). From Fig. 5-b, it is clear that there is a drop in the overall throughput, if the number of relays is increased (200m inter-node distance). The main reason for that is the poor performance of STBC codes in uncorrelated environments. In this case routing (AODV) performs better than cooperative relaying, for both scenarios (200m-140m).

C. Grid topology with random non-cooperative relays

The scenarios described in III.B are simulated in a 6x6 grid topology with varying relay densities for both propagation environments. The non-cooperative relay nodes are randomly added in the middle of the grid nodes. The simulation results are given in Fig. 6.

a) Randomly placed non-cooperative relays for Channel A

b) Randomly placed non-cooperative relays for AWGN channel

Fig. 6. Grid topology with randomly placed non-cooperative relays

Fig. 6-a clearly shows that using non-cooperative relays in a Channel A propagation environment improves the network performance for low network densities. In Fig. 6-a, for the 18m node spacing, the performance of the network with 5 and 8 randomly placed relaying nodes is better than that with pure AODV. Even though there is an increase in performance for fewer relaying nodes, placing more than 5 non-cooperative relay nodes decreases the performance due to the interference caused by the additional relaying nodes. On the other hand, for high network density scenarios (node spacing 14m), the performance of the network with pure routing is better than

that with relaying enabled, because routing (AODV) uses fewer nodes for forwarding than relaying, whereas the scenarios with relaying methods use static routes with fixed number of hops.

Fig. 6-b shows the performance of the random non-cooperative relays versus the dynamic routing protocol for the 6x6 grid topology in uncorrelated propagation environment. For low node densities, the dynamic routing protocol suffers from link breakages and performs worse than the scenarios with random relays. Although it has been shown in [13] that the non-cooperative relaying doesn't perform well in AWGN channels, deploying non-cooperative nodes in low density networks helps to improve overall system performance. For the AWGN channel case scenario with 140m node spacing used, AODV outperforms the network with random number of relaying nodes deployed, because interference caused by extra relaying nodes degrades the performance of the network.

V. CONCLUSIONS AND FURTHER WORK

Our simulation results confirm that the use of relays can increase the network throughput as well as coverage of wireless ad-hoc networks, in particular in low-density relay scenarios. In some scenarios the network performance with dynamic routing without relaying was comparable or better than that with relaying enabled in the network. When considering the increased complexity required to make the co-operative relaying techniques to work, the overall performance improvement brought by relaying may not be significant to justify deploying it when comparable results could be achieved with established routing techniques.

The use of cooperative relays in free space propagation environments degrades the N-SAP throughput, due to the worse BER performance of STBC systems in these environments. There is a considerable increase in network throughput in multi-path propagation environments.

When the non-cooperative relaying nodes are randomly distributed in the grid topology (Fig. 3-c), the overall throughput of the network with relaying is better than the network with dynamic routing running over a non-relaying system at low density. This is true for both propagation models used in the simulations. The overall throughput of the network decreases with the increasing number of randomly placed non-cooperative relaying nodes, which is expected due to the increased interference caused by the extra relaying nodes.

The throughput improvement due to the use of co-operative and non-cooperative relaying strongly depends on the network density, topology, the routing method and the propagation environment. It is important to note that the increased network (N-SAP) throughput has been achieved when using static routing with optimal matching between the relay forwarding decisions and the established routing paths. This certainly is not expected to be true in dynamic networking systems *unless* solutions are designed to cater for this. The strong and varying dependency on several factors clearly shows that assigning and

managing relays for wireless networks using dynamic routing protocols remains a significant challenge if one wants to ensure that the overall system performance is improved rather than otherwise.

VI. ACKNOWLEDGMENTS

The work reported in this paper is part of the OSIRIS project within the 3CR Research programme on convergent technology for digital media processing and communications, whose funding and support is gratefully acknowledged. For more information, please visit www.3cresearch.co.uk.

BIBLIOGRAPHY AND REFERENCES

- [1] J. Z. Sun, J. Sauvola, D. Howie, "Features in future: 4G visions from a technical perspective," Global Telecommunications Conference, 2001. GLOBECOM'01, IEEE, Volume:6, 25-29, Nov. 2001, pp:3533 - 3537 vol.6
- [2] Mischa Dohler, "Virtual Antenna Arrays (VAA)", Phd Dissertation, King's College London, 2003.
- [3] Michael Gastpar, Martin Vetterli, "On the Capacity of Wireless Networks: The Relay Case", IEEE Infocom, 2002.
- [4] A. Sendonaris, E. Erkip, B. Aazhang, "Increasing Uplink Capacity via User Cooperation Diversity", Proc. IEEE ISIT, p. 196, August 1998.
- [5] A. Sendonaris, E. Erkip, B. Aazhang, "User Cooperation Diversity – Part I: System Description," IEEE Transactions on Communications, vol. 51, no. 11, November 2003, pp. 1927-1938.
- [6] A. Sendonaris, E. Erkip, B. Aazhang, "User Cooperation Diversity – Part II: Implementation Aspects and Performance Analysis," IEEE Transactions on Communications, vol. 51, no. 11, November 2003, pp. 1939-1948.
- [7] IEEE Std 802.11a/D7.0-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High Speed Physical Layer in the GHz Band."
- [8] S.M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, pp. 1451-8, 1998.
- [9] A. Molina, E. Tameh, and A. Nix, "The Optimisation of Fixed Relay Locations to Enhance the Performance of a 3G Microcellular Network", IST, June 2004, Lyon
- [10] J. Nicholas Laneman "Cooperative Diversity in Wireless Networks: Algorithms and Architectures", PhD Dissertation, Massachusetts Institute of Technology, 2002.
- [11] J. Medbo and P. Schramm "Channel Models for HIPERLAN/2" ETSI/BRAN doc. no. 3ERI085B, 1998.
- [12] <http://www.scalable-networks.com>
- [13] S. Gormus, D. Kaleshi, J.P. McGeehan, A. Munro, "Performance Comparison of Co-operative and Non-cooperative Relaying Mechanisms in Wireless Networks", WCNC'06, Las Vegas, April 2006.
- [14] Piyush Gupta and P.R. Kumar, "The capacity of wireless networks", IEEE Trans. Inform. Theory, 46(2):388-404, March 2000.
- [15] Elizabeth M. Royer, C-K Toh, "A review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks", IEEE Personal Communications Magazine, 6(2):46-55, April 1999.
- [16] C. E. Perkins, E.M. Royer, "Ad-hoc On-Demand Distance Vector Routing", 2nd IEEE Workshop on Mobile Computing Systems and Applications, Proc. Of, pp.90-100, New Orleans, LA, February 1999.
- [17] J. N. Laneman and G. W. Wornell, "Energy-Efficient Antenna-Sharing and Relaying for Wireless Networks", IEEE Wireless Communications and Networking Conference (WCNC-2000), (Chicago, IL), September 2000.