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Performance Evaluation of Network Coding in Wireless Ad Hoc Networks

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Abstract*— Broadcast and multicast operations which disseminate information network wide are important features in multi-hop wireless networks. This work shows how network coding can be applied in wireless in ad hoc networks. We focus on broadcast traffic and design a network coding-based scheme that we compare against simpler solutions, through extensive simulations. Our goal is to assess the performance of the proposed network coding scheme in wireless ad hoc networks in both realistic MAC and physical are considered and when mobility of nodes is considered as well. The performance analysis of the proposed network coding scheme on broadcasting traffic is strongly depends on the network node density and the generation size. Network coding brings no benefits to be implemented and run in sparse networks. On the other hand, network coding performs well and has significant gains in terms of end-to-end packet loss probability in dense networks. Moreover, achieved results show that the protocol delivers broadcast data reliably with minimal network overhead, by eliminating redundant data transmissions, even under adverse network conditions.

***Index Terms*—Ad hoc networks, traffic broadcasting, network coding.**

I. INTRODUCTION

Mobile ad hoc networks (MANETs) are continuously self-configuring mobile wireless networks where nodes organize and maintain the network by themselves without any on preexisting infrastructure to communicate. Broadcasting is a communication operation in which one node transferring a message to all recipients in the network simultaneously. Broadcasting is used in mobile ad hoc network with different aims such as broadcast control packets during route discovery to find a route to a particular node, broadcast a warning signal, broadcast topology update packets to perform service discovery, and to broadcast the user data packets. Flooding is the simplest method to implement broadcasting, where any node in the network forwards the message to every other node in the vicinity (to all neighbors) upon receiving the message for the first time. Flooding, is usually very costly, and leads to undesired effects such as broadcast storm problem: where straightforward broadcasting resulting in serious redundancy, contention, collision, and extra-power consumption [2]. Many broadcast sophisticated solution have been proposed in order to solve the above shortcomings, such as probabilistic-based [12], [2], neighbor knowledge-based [4], counter-based [2], location-based [2], and distance-based [2]. In this paper we consider the problem of broadcasting in a mobile ad hoc wireless network, and assessing the performance by using the proposed network coding scheme. This technique was given and introduced in [3], where network coding allows nodes to combine multiple packets into a single one before forwarding, such technique can indeed reduce the network overhead. Several papers, e.g.,[26] [10], [11],have been published to propose and fundamentally advance the area of network coding such as providing high reliability, bandwidth gains, reduced delays and better traffic distribution, such advances will lead to both *load balancing and better energy efficiency*. However, the earlier works have shown the benefits of network coding either via hypocritical studies, or simplified simulations tools and scenarios. In our work we analyze and study the performance of network coding using the realistic simulation tool ns-2 [19] in a realistic ad hoc environment and scenario. In our proposed network coding scheme, all nodes in the network (source node and intermediate nodes) combine native packets and encode them by using the random linear network coding before broadcasting them to all other downstream nodes. In our study, we compare and analyze the performance of the proposed network coding scheme against the other broadcasting schemes in comparison, namely simple flooding and differed broadcasting. The results of our preliminary study are reported in [6] [7] [8]. In this paper, in order to account for more realistic scenarios, we modeled the channel propagation through the Rayleigh distribution [9] which accounts for multipath effects and time varying channel conditions. Using realistic MAC and physical layers, we can observe and study the effects of packets loss probability and propagation delay on network coding. Certainly, firstly, a single packet loss at the receiver side will invalidate the encoded information, thus it has potential impact to cause multiple packet loss. Secondly, delay is due to many different factors in MANET, typically due to multihop communication in the network, the destination has to wait until it receives all packets that are encoded together, before performing the decoding. Finally, the source node has to buffer the packets coming from its application layer before encoding and broadcasting them to the downstream nodes. The impact of nodes mobility on the performance of the deployed algorithms is considered as well.

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II. RELATED WORK

In-order to improve the performance of network coding, many solutions have been proposed, in this section we focus on the proposed solutions to improve the efficiency of network coding in ad-hoc networks, especially for broadcasting traffic. A probabilistic based transmission approach [2], which is widely used; where a traffic source node broadcast messages, other nodes rebroadcasting messages with a certain probability. The advantage of this method in comparison to simple flooding, is reducing the overhead, in the contrary, it may lead to low delivery probability especially in sparsely connected nodes. In counter-based approach [2], a node broadcast a message based on the number of received copies of the broadcast message. In distance-based scheme [2], a node decides whether to rebroadcast a message or not, based on the distance between the node and the previous sender. This scheme, promote neighboring nodes who are located far from the sender to rebroadcast the messages. In [4] the authors enhance the previous work in [2], by adaptively adjusting the probability of transmission or delay timer by taking local connectivity information into account. Similarly, in [5], the rebroadcast probability is dynamically calculated based on the number of neighbor nodes of every host. However, local connectivity knowledge is hard to maintain especially in a mobile environment. Many solutions have been proposed for broadcasting in network coding, where [14], only subset of nodes are selected as forwarders, which performs network coding functionality, more over in such scheme, a forwarder can decide not to forward the packet as it learns, via promiscuous mode, that all its neighbors have received the packet. Although, the proposed scheme in [14] has better performance, it is depends on the neighboring exchanged information, and on the pruning algorithm as presented in [15], which may increase the overhead significantly and add more complexity relative to other probabilistic proposed schemes. A network coding re-transmission scheme based on the randomized broadcast is proposed in [16], where network coding parameter are selected and tuned for grid topology to increase the packet delivery ratio in comparison to simple flooding. However, such benefits can be only in dense network, where the loss probability is due to high collisions rate. Moreover, [17] analysis the impact of IEEE 802.11-based MAC protocols on the performance of broadcasting in network coding scheme. Moreover, the authors in [18] analyzed the performance of network coding for broadcast communications and evaluated the obtained gain in different typologies using network coding, with different offered loads. However, till now the majority of works on network coding are theoretical frameworks and analytical studies. As an example, the study conducted in [27] tried to answer the question of how much network coding coupled with wireless broadcasting may potentially improve the performance in terms of throughput and energy efficiency in multihop networks. They analytically prove that in the case of a square random deployed wireless networks, when the intermediate nodes perform network coding with broadcasting, the throughput benefit ratio of the coding scheme, defined as the ratio between the throughput capacity of the coding scheme to the throughput capacity of non-coding scheme, is expected to be proportional to the average number of neighbors. Conversely, in practice they have shown that a constant factor of improvement in throughput can be achieved. Moreover, the authors derive the boundaries for such improvement factor, which roughly has a value of 2. In [29] authors show that the theoretical upper bounds of the coding gain derived by the study carried out in [27], by constructing best-case coding scenarios, can be far from achievable in case of general topologies and traffic patterns. Apart from the aforementioned metrics, a fundamental key performance in realistic cases is the maximum number of packets that can be encoded together by any intermediate node in each transmission referred to as encoding number. Both studies in [28] and [30] dealt with this issue, showing that the encoding number is quite small, at most 5, and in most cases, only 2 to 4. Based on our knowledge, only few works exists for practical network coding scenarios using realistic network simulators e.g., [17], [23]. Thus, our goal is to study and analyze the performance of network coding based broadcast communications by using the realistic simulation tool NS-2. Furthermore, we implement our proposed network coding scheme that does not need any knowledge and corporation between their two-hop neighbors; we compare our proposed network coding scheme, against both simple flooding and deferred broadcasting scheme, the later scheme is proposed in [13]. The proposed random linear network coding is deeply described and discussed in our earlier work[1], where we described in details the network coding operations and implementations, however, the other broadcasting schemes in comparison also described in our earlier work.

III. PERFORMANCE EVALUATION

A. Simulation Settings

To evaluate the performance of the proposed network coding scheme, which is in ns-2 simulator? We used the IEEE 802.11 protocol at the MAC layer with the 1 Mbps data rate. Further configurations and considerations are stated below:

1) One node is selected to be a source of data, which generates at the application layer a CBR traffic, where all packets have the same size of 1000 bytes, with a fixed traffic rate set to 50 kbps.
2) The Network Coding buffer NC is set to one second, which represents the maximum buffering timeout.

To analyze the performance of network coding based broadcast, we collect two kinds of results. The first set of results are derived by considering 100 static nodes uniformly distributed and deployed within a squared area of 100 × 100 m. This set of results and discussion about them are shown in our earlier work [1]. An addition metric is introduced (namely early decoding gain) for analysis the network coding

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performance on static nodes. Also two encoding policies (*x1-encoding and x2-ecoding*) are defined and introduced.

The second set of results are computed by considering in the same area 100 nodes which move according to the well-known and widely used Random Waypoint Model, RWP, [21]. At the beginning of a simulation, the Random Waypoint mobility model randomly places the nodes within the predefined simulation area. Every mobile node begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, it chooses a random destination in the simulation area and a speed that is uniformly distributed between (*minspeed*, *maxspeed*). The mobile node then travels toward the newly chosen destination at the selected speed. Upon arrival, the node pauses for the specified pause time before starting the process again. At the end of the pause time, it selects a new destination and speed combination, and then resumes movement. Specifically, in our simulations the speed of the mobile nodes is uniformly chosen between 0 and 2 m/s. Both the well-known Two-ray Ground Model, which accounts for near-ideal propagation conditions, and the Rayleigh fading model [22], which models realistic propagation conditions, by accounting for multipath effects and time-varying channel conditions, are used as propagation models. We perform our analysis through simulations, assuming nodes with homogeneous transmission range and deployed on a bounded area. Such configurations lead to the well-known *border effect* problem [20]. Moreover, it is clear that when adding mobility such as RWP model, the nodes distribution will not be uniform. A node most likely to be in the center of the area. In order to eliminate the effects of nodes in the border, both in static and mobile configurations, we introduced a simple modification to our reference topology. We calculate the node's transmission range, Tx, to get the specific neighborhood size. Then, a new topology is considered by increasing simulation area sides by a distance equal to Tx. By knowing the latter value and the area for the new deployed topology, we calculate the number of nodes to be uniformly distributed in the new area achieving the same previously considered neighborhood size. For our statistics we consider only the 100 nodes which are located in the center of the topology and are almost distributed within an area of 100 × 100 m. Figure 1 shows the network topology we built by considering the border effects. It should be noticed that any new node added to the network topology has the same functionality like others even though it is not considered in the statistics computation.

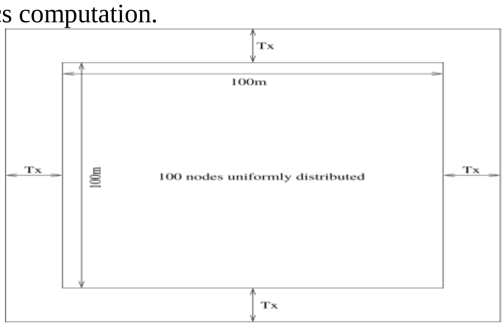

Fig 1 Simulation topology, considering the border effects

Different metrics have been used to assess the broadcast schemes, namely; packet loss probability, end to end E2E delivery delay, transmission fairness, and the protocol overhead. More in details, the last metric is defined as the ratio between the total numbers of bytes transmitted by all nodes in the scenario including the source to the total number of bytes generated at the application layer of the source node. Such metric can be used as an indicator of the energy consumption for the broadcast scheme by the entire network nodes, since the protocol overhead metric counts the total number of bytes to transmit the packet. The simulation output data are averaged over 5 runs with different seed numbers, and random distributions of network typologies.

B. Simulation Results

The performance of the proposed network coding scheme is represented in this sub-section, where we consider different values of the generation sizes, namely s = 2, 3, 4, the results are showed and discussed against the other broadcasting schemes in comparison; which are the simple flooding and the deferred broadcast. Moreover, for an in-depth analysis of the main features of the network coding technique, we vary the number of encoding operations made by intermediate nodes to be either once or twice per generation. **Static nodes under the two-ray ground propagation**. We start by looking at the results achieved in a static scenario, when the two-ray ground propagation model is considered. The packet delivery delay metric, which is an averaged value, is defined as the time elapsed from the instant the packet being generated at the source side, till it being received at the destination node, is depicted in Figure 2. We can observe that the delay decreases as the number of neighbor nodes increases (due to the increase of the radio range), it is clear that wider radio range yields to fewer hops, thus it cause lower delay.

With focus on the network coding performances, we define an additional metric, the early decoding gain, which is defined as the ratio between the average number of packets that are only decoded due to the early decoding operation, to the average number of packets that are decoded due to both an early decoding and a full rank decoding operations. Such a metric shows how much the early decoding operation can improve the packet delivery performance. By looking at Figure 3 we can notice that for neighborhood size greater than 8, the higher is the generation size, the higher is the gain. This is because the use of a higher generation size, by reducing the number of innovative packets, reduces the probability that nodes will receive all innovative packets in a given generation. Therefore, nodes are hindered to perform a full rank decoding, and the use of the early decoding enables to decode more packets.

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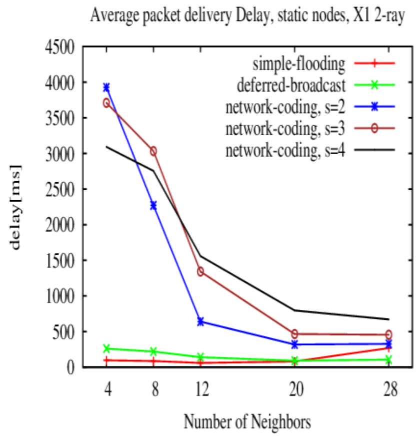

Fig 2 Packet delivery delay based on the neighborhood size

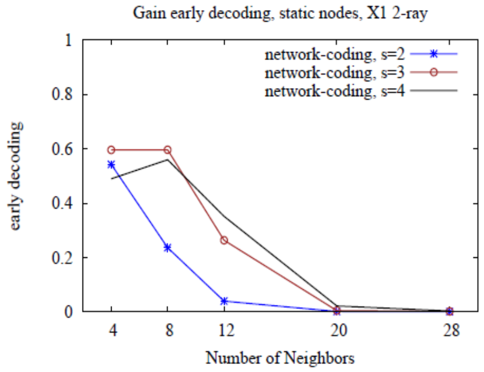

Fig 3 Early Decoding Gain as a function of the neighborhood size

In low dense network, i.e., neighborhood size is equal to 4, and when generation size is equal to 4, probability as well. Thus, source neighbors are able to receive the broadcasted packets (by the source) correctly, and they will be able to perform the full rank decoding. Moreover, they have a higher chance to perform the full rank decoding as compared to other nodes in the network. In fact, the other non-isolated nodes in the sparse network may get advantage from an early decoding by retrieving some innovative packets from the partially received innovative encoded packets in a given generation. However, the total number of decoded packets which are retrieved and decoded by full rank decoding is extremely high compared to those ones which may be retrieved under an early decoding operation. The above statement explains the lower values of gain experienced for neighborhood size equal to 4 and 8. On the other hand, the increase of the neighborhood size will decrease the gain, because nodes have more chances to receive enough innovative packets to perform a full rank decoding. We do not show the results obtained when adding mobility or changing the propagation model, because they are qualitatively equivalent for the analysis. **Mobile nodes against static nodes scenario under two-ray ground propagation**. We will continue by comparing the performances of simple flooding and network coding-based scheme in static and mobile scenarios. By looking at Figure 4, we can notice that mobility slightly increases the end-to-end delay.

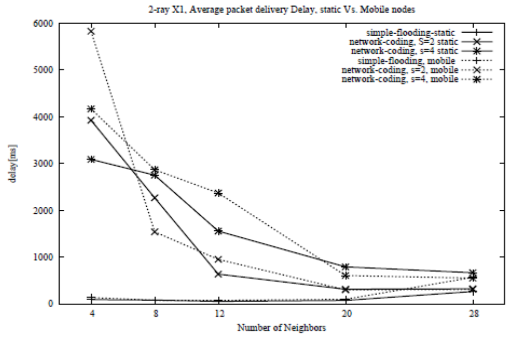

Fig 4 Packet delivery delay based on the neighborhood size

This can be explained as follows. Differently from a static wireless multihop network, where an isolated node fails in receiving any information from nearby nodes, and, in turn, fails in rebroadcasting a packet, which become useless for communication with all other nodes, while in a mobile scenario, an isolated node can contribute in the communication and it can receive packets when it moves in the transmission range of other node, or when other nodes passes by. This allows increasing the packet delivery, but at the same time this might because a higher packet delivery delay, as already noticed in [24]. In very sparse network the mobility has a positive effect on connectivity, whereas in dense network the situation becomes the opposite [25]. Such a trend is noticed for flooding performances and it is witnessed by the lower values of packet loss probability achieved in sparse network with respect to the static scenario. Conversely, for high dense networks losses increase with respect to static scenario, see Figure 5.

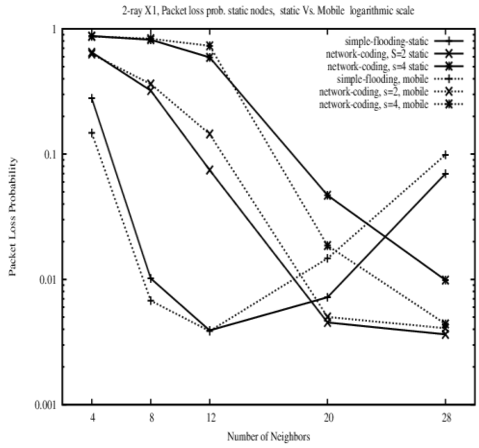

Fig 5 Packet loss probability based on the neighborhood size

As for the static nodes scenario, the minimum value of packet loss is experienced for flooding scheme under medium density conditions, where the number of neighbor is high enough to ensure a good connectivity level and low enough to hinder the occurrence of collisions. Network coding can benefit of mobility as well, but only for high values of generation size and neighborhood size, as well. Indeed, when network coding-based broadcasting is applied with generation size equal to 4, the intermediate nodes are required to wait more time to get all native packets within a given generation or till buffer is timed out before forming any possible random

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combination. Thanks to the node movements, nodes have chances to receive more packets within their waiting time. Instead, when only two packets are encoded together per generation, network coding cannot benefit of the mobility of nodes, since the waiting times before the encoding procedure are significantly shorter than in case of generation size equal to 4. Again, starting from neighborhood size equal to 20, broadcasting based on network coding with generation size equal to 2, outperforms simple flooding. The positive effect of mobility on the connectivity of the network is witnessed by the higher values of overhead and fairness with respect to static scenarios for neighborhood size equal to 4, see Figure 6 and Figure 7.

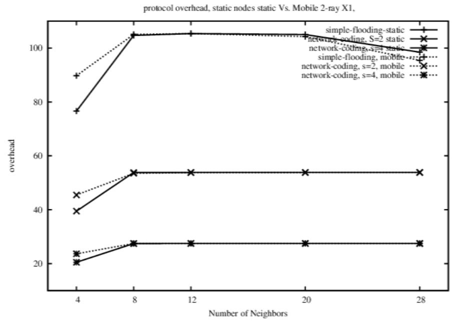

Fig 6 Protocol overhead based on the neighborhood size

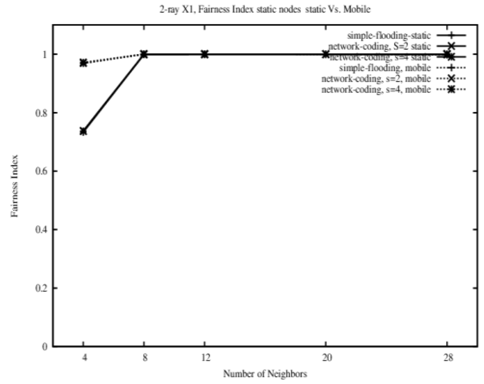

Fig 7 Fairness index based on the neighborhood size

For higher values of neighborhood size, mobility does not affect the values of the overhead and fairness metric, which present the same trends already seen for the static scenario. **Effect of encoding policy**. In our scheme we consider both cases when intermediate nodes can perform encoding only once or twice over the same generation. For the sake of notation we refer to the first policy as x1-encoding, and to the second one as x2-encoding. The x2-encoding policy can bring more benefits as compared to x1-encoding policy. However, we notice such a gain only in terms of packet delivery and for high generation sizes, see Figure 8 and Figure 9. Indeed, negligible losses are achieved.

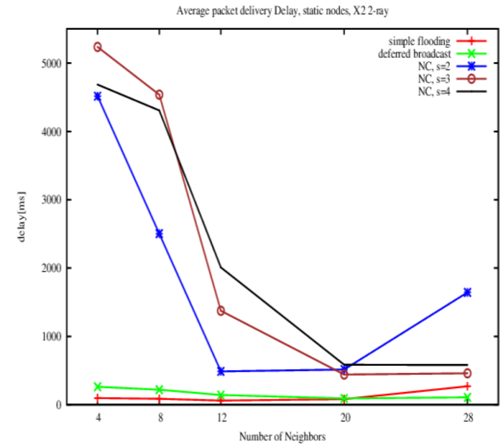

Fig 8 Packet delivery delay based on the neighborhood size

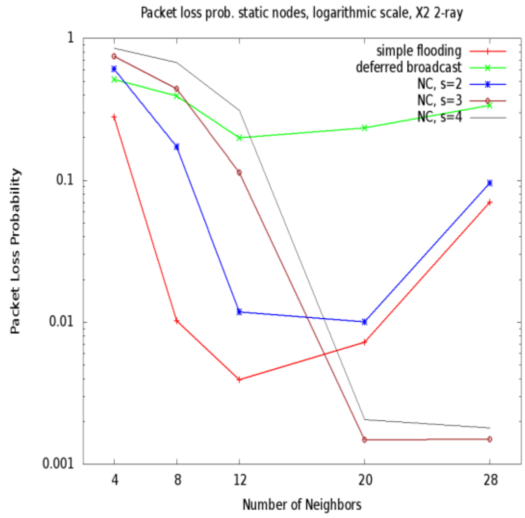

Fig 9 Packet loss probability based on the neighborhood size

Instead, for generation size equal to 2, the behavior of x1-encoding is similar to the one exhibited by simple flooding, but slightly worse.

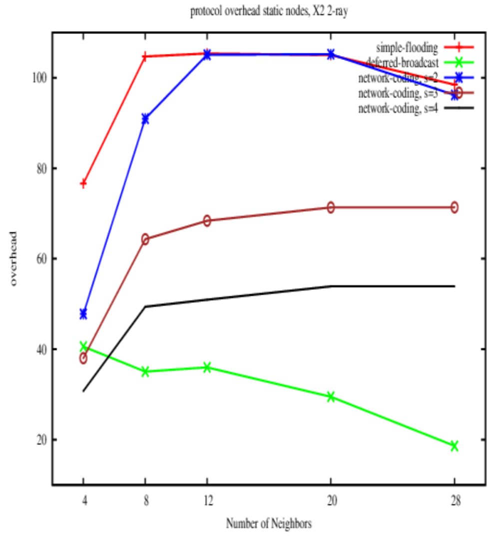

Fig 10 Protocol overhead based on the neighborhood size

As we can expect, the benefits are achieved at the expenses of higher overhead values which are almost doubled, with

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respect to x1-encoding, Figure 10. Notwithstanding, the network resources required by network coding-based broadcasting are again lower than the one exhibited by the flooding policy. No remarkable differences are noticed for the fairness metric with respect to the x1-encoding policy, Figure 11.

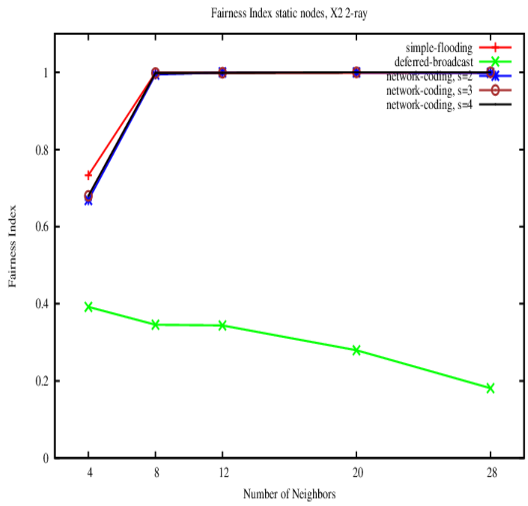

Fig 11 Fairness index based on the neighborhood size

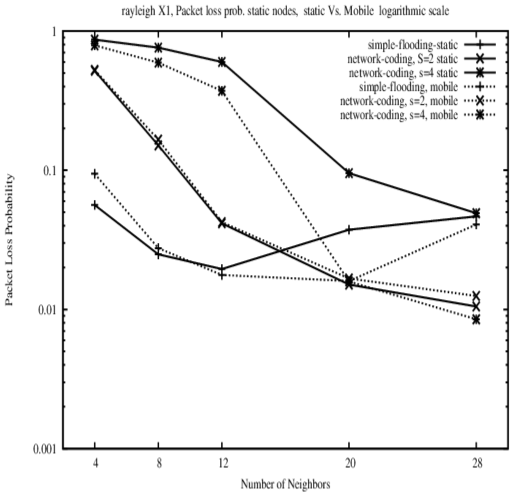

Fig 12 Packet delivery delay based on the neighborhood size

Mobile nodes against static nodes scenarios under Rayleigh propagation. The overall performances of the evaluation metrics under the Rayleigh propagation scenario do not substantially change with mobility, as already noticed for the two-ray ground model. By looking at Figure 12 we can observe that mobility slightly increases the packet delivery delay for all the deployed schemes. Reasons are the same already discussed when comparing static and mobile scenarios, under the two-ray ground propagation model. As regards the packet loss probability, Figure 13, differently from the behavior exhibited by flooding under two-ray ground propagation, where mobility increases the connectivity for sparse network and adversely affects the packet delivery for dense network, the coupling of mobility and harsh realistic propagation conditions results in an inverse trend.

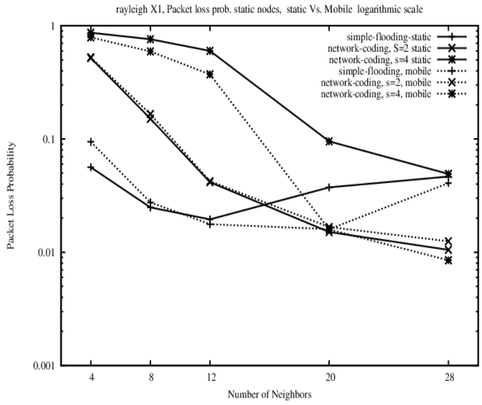

Fig 13 Packet loss probability based on the neighborhood size

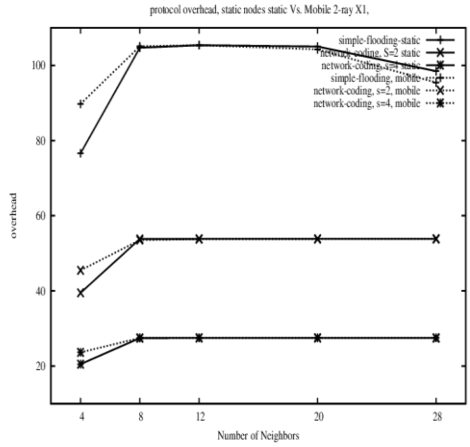

Fig 14 Protocol overhead based on the neighborhood size

Indeed, for low density scenarios mobility of nodes is not enough to cope with channel-induced losses, thus, the mobile scenario exhibits higher packet loss probability with respect to the static one.

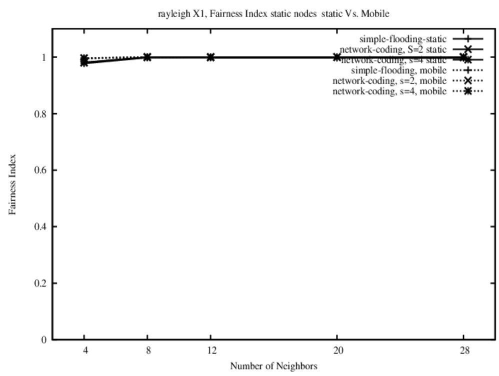

Fig 15 Fairness index based on the neighborhood size

For the near-ideal two-ray ground propagation model, we have seen that for high value of neighborhood size, mobility contributes in increasing the connectivity degree, this resulting in a more congested network, where packet loss probability is high mostly due to collisions. Conversely, when considering the Rayleigh propagation model, the better connectivity provided by the mobility of nodes, is able to counteract channel-induced losses, while simultaneously keeping low the collision events.

For network coding-based broadcast with generation size equal to 4, as for the two-ray ground propagation model, mobility has a positive impact on the delivery ratio. Again, for small generation size equal to 2, almost the same behavior is recorded for both settings, mobile and static one. No remarkable differences between static and mobile scenarios are experienced by the overhead and fairness metric, as shown in Figure 14 and Figure 15, respectively.

IV. CONCLUSION

The performance analysis of the introduced network coding-based scheme reveals that the generation size and the network density are the main factors that dominates on the performance of the network coding approach under study. Network coding has a better performance relative to other schemes in comparison in terms of protocol overhead and end-to-end packet loss probability just for dense network with large neighborhood size with small generation size under x1-encoding policy. On the contrary, in smaller neighborhood size, the x2-encoding policy has better performance. The protocol is able to reliably deliver broadcast packets even under adverse network conditions. The impact of mobility of network coding is evaluated as well. Results show that mobility can help in lowering the packet loss probability for high value of generation size. As future work, we intend to study the Performance of network coding in ad hoc network multipath routing protocols.

REFERENCES

[1] Tarapiah, Saed and Atalla, Shadi and Masri, Ahmed, "Analysis the Performance of Network Coding for Ad Hoc Networks in Realistic Simulation Scenarios," in International Journal of Computer Applications, vol. 85, no. 10, pp. 13-20, 2014.

[2] S. Ni, Y. Tseng, Y. Chen, and J. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Networks," in ACM MobiCom, Aug. 1999.

[3] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung, "Network Information Flow," in IEEE Trans. Inform. Theory, vol. 46, no. 4, pp. 104-1216, July 2000.

[4] Y. Tseng, S. Ni, and E. Shih, "Adaptive Approaches to Relieving Broadcast Storms in a Wireless Multihop Mobile Ad Hoc Network," in IEEE Transactions on Computers, vol. 52, no. 5, pp. 545-557, May 2003.

[5] A.H. Hanashi, A. Siddique, I. Awan, and M. Woodward, "Performance Evaluation of Dynamic Probabilistic Flooding in Mobile Ad Hoc Networks," in Simulation Modelling Practice and Theory, vol. 17, pp. 364-375, 2009.

[6] Tarapiah, S. and Casetti, C. and Chiasserini, C., "Network Coding in Ad Hoc Networks: A Realistic Simulation Study," in INFOCOM Workshops 2009, IEEE, pp. 1-2, 2009.

[7] C. Campolo, S. Tarapiah, C. Casetti, C.F. Chiasserini, "Performance of Network Coding for Ad Hoc Networks in Realistic Simulation Scenarios," in Proc. of IEEE International Conference on Telecommunications, ICT, 2009.

[8] Tarapiah, Saed and Atalla, Shadi and Masri, Ahmed, "Analysis the Performance of Network Coding for Ad Hoc Networks in Realistic Simulation Scenarios," in International Journal of Computer Applications, pp. 13-20, 2014.

[9] T.S. Rappaport, "Wireless Communications: Principles and Practice," Prentice Hall, 1996.

[10] C. Fragouli, J.-H. Le Boudec, and J. Widmer, "Network Coding: An Instant Primer," in ACM SIGCOMM Computer Communication Review, vol. 36, no. 1, pp. 63-68, Jan. 2006.

[11] C. Fragouli, J. Widmer, and J.-I. Le Boudec, "Efficient Broadcasting Using Network Coding," in IEEE/ACM Trans. on Networking, vol. 16, no. 2, Apr. 2008.

[12] Z.J. Haas, J.Y. Halpern, and L. Li, "Gossip-based ad hoc routing," in IEEE/ACM Trans. on Networking, vol. 14, no. 3, pp. 479-491, June 2006.

[13] V. Naumov, R. Baumann, and T. Gross, "An Evaluation ofInter-Vehicle Ad Hoc Networks Based on Realistic Vehicular Traces," in ACM MobiHoc, May 2006.

[14] L. Li, R. Ramjee, M. Buddhikot, and S. Miller, "Network Coding-Based Broadcast in Mobile Ad Hoc Networks," in IEEE INFOCOM, 2007.

[15] W. Lou, and J. Wu, "On Reducing Broadcast Redundancy in Ad Hoc Wireless Networks," in IEEE Trans. on Mobile Computing, 2002.

[16] T. Matsuda, T. Noguchi, and T. Takine, "Broadcasting with Randomized Network Coding in Dense Wireless Ad Hoc Networks," in IEICE Trans. on Communications, vol. E91-B, no. 10, pp. 3216-3225, 2008.

[17] E. Fasolo, M. Rossi, J. Widmer, and M. Zorzi, "On MAC Scheduling and Packet Combination Strategies for Practical Random Network Coding," in IEEE ICC 2007, Glasgow, UK, Jun. 2007.

[18] Prashanthi, V. and Babu, D.S. and Guru Rao, C.V., "Network coding-based communication in wireless ad-hoc networks," in Communications and Signal Processing (ICCSP), 2014 International Conference on Communications and Signal Processing (ICCSP), 2014, pp. 1040-1044.

[19] The Network Simulator, ns2. http://www.isi.edu/nsnam/ns/

[20] C. Bettstetter, and J. Zangl, "How to achieve a connected ad hoc network with homogeneous range assignment: an analytical study with consideration of border effects," in 4th Int. Workshop on Mobile and Wireless Communications Network, 2002, pp. 125–129.

[21] J. Broch, D. A. Maltz, D. Johnson, Y.-C. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," in Proc. of the Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), pp. 85–97, Dallas, Texas, October 1998.

[22] R.J. Punnoose, P.V. Nikitin, and D.D. Stancil, "Efficient Simulation of Ricean Fading within a Packet Simulator," in Proc. of IEEE Vehicular Technology Conference, pp. 764–767,2000.

[23] Chu, Xiaowen and Zhao, Kaiyong, "Practical random linear network coding on GPUs," in Lecture Notes in Earth System Sciences, Springer Berlin Heidelberg, pp. 115-130, 2013.

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[24] C. Bettstetter, "On the Minimum Node Degree and Connectivity of a Wireless Multihop Network," in Proc. of the 3rd ACM international symposium on Mobile ad hoc networking and computing, pp. 80–91, 2002.

[25] P. Lassila, E. Hyytia, and H. Koskinen, "Connectivity Properties of Random Way Point Mobility Model for Ad Hoc Networks," in Proc. MedHoc-Net, Ile de Porquerolles, pp. 159– 168, 2005.

[26] Sadeghi, Parastoo and Yu, Mingchao, "Instantly Decodable versus Random Linear Network Coding: A Comparative Framework for Throughput and Decoding Delay Performance," in CoRR, 2012.

[27] J. Liu, D. Goeckel and D. Towsley, "Bounds on the Gain of Network Coding and Broadcasting in Wireless Networks," in IEEE INFOCOM, May 2007.

[28] S. Katti, H. Rahu, W.J. Hu, D. Katabi, J. Crowcroft, "XORs in the air: practical wireless network coding," in ACM Sigcomm'06, Pisa, Italy, 2006, pp. 243-254.

[29] D. Koutsonikolas, Y. C. Hu, C.-C. Wang, "An Empirical Study of Performance Benefits of Network Coding in Multihop Wireless Networks," in IEEE INFOCOM Mini-Conference, Rio de Janeiro, Brazil, 2009.

[30] J.L. Le, J.C.S. Lui, D.M. Chiu, "How many packets can we encode? An analysis of practical wireless network coding," in IEEE INFOCOM, pp. 371-375, 2008.

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