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Throughput Analysis of WLAN with Network Coding

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***Abstract*—Network coding is a new concept of combining the information at intermediate nodes, which can increase the throughput of the network. In this paper we apply network coding techniques to Wireless LAN (WLAN). Network coding is applied at the access node of a 7-cluster WLAN and the probability of network coding feasibility is arrived at. Further queuing theory is applied to analytically obtain the WLAN throughput both in the presence as well as absence of physical channel induced transmission errors. From the analysis it is observed that application of network coding to WLAN increases the throughput by 5 to 7% as compared to traditional store and forward routing.**

***Index Terms*—Network coding, opportunistic listening, packet loss, throughput, wireless LAN.**

I. INTRODUCTION

NETWORK CODING, in simple terms, is a technique that relies on combining independent packets at intermediate nodes and then forwarding them such that they could be recovered at their respective destinations. The technique is considered by several researchers as an extension of the traditional store and forward paradigm and can effectively reduce packet density in communication networks. More details on network coding can be found in [1]-[8].

In [9], a model to find the stable throughput for wireless LAN with symmetric unicast flows based on slotted dynamic access MAC protocol using network coding was proposed. Their model was based on certain assumptions as follows. Network coding was used only at the access node (or the relay). All the nodes were based on a multi-class open queuing model with a constraint that overall arrival rate at a system is less than or equal to the departure rate from the system. With this constraint, Iraji et al [9] define stable throughput as maximum packet generation rate at which the packets reach their destinations with finite delay.

Though the work reported in [9] is of relevance and interest to the research community, several limitations do exist in their approach which is worth addressing. These limitations are listed below:

- Packet loss was solely due to collision but the channel was assumed to be error free. This need not be the case in practice
- In the analysis, though COPE [5] is the method used, packets were always assumed to exist in pairs conducive to network coding. However, in reality, this need not be true [5, 10].

Consequently, the throughput results provided in [9] using their network coding model is highly optimistic. To obtain more accurate throughput and thereby arrive at a more reliable assessment of the network capability, we extend and improve the model proposed in [9]. In this work, we consider packet loss in the network due to collision *as well as* channel induced errors. Also, availability and/or non availability of pairs of packets conducive to network coding (COPE [5]) is considered.

II. ANALYSIS OF WLAN

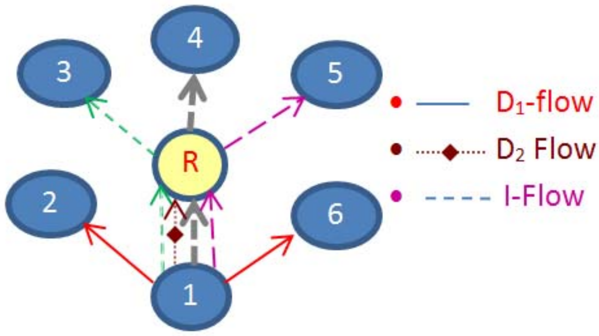

Fig. 1. WLAN showing different flows from node 1

Consider a WLAN with 7 nodes as shown in Fig. 1. We adopt a similar model as in [9]. There are six independent source/sink nodes called terminal nodes denoted as i, for all i=1,2,..6. The transmission range of any node is one hop. The packet destined to a node which is more than one hop distance is to be forwarded by access node 'R' (relay node). The node when transmits packets cannot receive any packet. The information arrival rate λ in the network is assumed to be uniformly distributed.

Throughput of the above WLAN with and without network coding in presence of packet loss due to collision and link error is analytically arrived at in the following discussions.

For convenience of analysis, we classify the flow of information in the network as follows.

- Direct flow 1 ($D1$): No involvement of access node
- Direct flow 2 ($D2$): Terminal node to access node
- Indirect flow (I): Terminal node to terminal node via access node.

Arrival rates of the different classifications of information flow discussed above can be arrived at as given below (see Table Ifor definitions of terms involved).

$$\alpha_{Flow} = New\ \ packet\ \ arriavl\ \ rate\ + .\alpha_{Flow}\ \ p(node\ \ failed\ \ to\ \ deliver\ ) \tag{1}$$

$$\alpha_{Flow\ type} = \frac{innovative\ packet\ arriavl\ rate}{1-p(\ node\ failed\ to\ deliver)} \tag{2}$$

$$\alpha_{Flow\ type} = \frac{innovative\ packet\ arriavl\ rate}{(packet\ succesfully\ delivered)} \tag{3}$$

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TABLE I: TERMS USED IN THE ANALYSIS

Parameter	Definition
$P_t = \frac{2}{(1+W)}$:	Average transmission probability at terminal node. (W is the contention window)
$P'_t = \frac{2}{(1+W')}$:	Average transmission probability at access nodes.
μ, μ':	Service rate of terminal nodes and access point
ρ, ρ':	Traffic intensity at terminal node and access point
λ:	Innovative Arrival rate or generation rate at terminal node.
α_{D1}:	Total Arrival rate at terminal node destined to its neighbor.
α_{D2}:	Total Arrival rate at terminal node destined to its access node.
α_I:	Total Arrival rate at terminal node destined to its terminal node has to be forwarded by access node.
p_l:	Packet loss due to errors (and not due to collision)

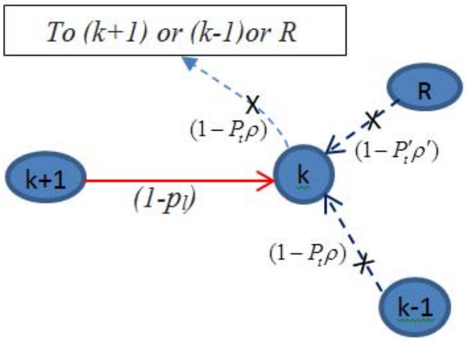

Fig. 2. Successful delivery of flow from node(k+1) to node(k).

The information flow from node (k+1) to node k is delivered successfully only if node (k-1), node k, and node (k+1) do not transmit and the packet does not suffer any loss due to errors as shown in Fig. 2.

At any terminal node the arrival rate for D1, D2, and I flows is obtained using equation (3) respectively as

$$\alpha_{D1} = \frac{\lambda}{6(1-P_t\rho)^2(1-P'_t\rho')(1-p_l)} \tag{4}$$

$$\alpha_{D2} = \frac{\lambda}{6(1-P_t\rho)^5(1-P'_t\rho')(1-p_l)} \tag{5}$$

$$\alpha_I = \alpha_{D2} \tag{6}$$

The total arrival rate at any terminal node is $2\alpha_{D_1} + 3\alpha_{D_2} + \alpha_I$, using equation (4-6), the overall traffic intensity at the terminal nodes can be shown to be

$$\rho = \frac{\lambda}{3\mu(1-P_t\rho)^2(1-P'_t\rho')(1-p_l)}\left(1+\frac{2}{(1-P_t\rho)^3}\right) \tag{7}$$

It may be noted that since network coding is not applicable at the terminal nodes in our model, (7) holds good with or without network coding.

Moving on to the access nodes, it can be easily seen that the overall traffic intensity without network coding is

$$\rho' = \frac{3\lambda}{\mu'(1-P_t\rho)^3(1-p_l)} \tag{8}$$

and the maximum throughput is

$$\lambda_{SR} = \frac{\mu'\rho'(1-P_t\rho)^3(1-p_l)}{3} \tag{9}$$

The overall traffic intensity and the maximum throughput at access nodes in the presence of network coding with opportunistic listening (COPE) can be arrived at as discussed in the appendix and is as given below

$$\rho'_{NC2} = \frac{\lambda[413-216(1-P_t\rho)^3(1-pl)]}{72(1-P_t\rho)^3(1-pl)[2-(1-P_t\rho)^3(1-pl)]} \tag{10}$$

$$\lambda_{NC2} = \frac{72\mu'\rho'(1-P_t\rho)^3(1-pl)[2-(1-P_t\rho)^3(1-pl)]}{[413-216(1-P_t\rho)^3(1-pl)]} \tag{11}$$

$$where\ (\rho \le 1; \rho' \le 1)$$

Note that in arriving at (10) and (11) above, we have considered a more practical scenario wherein not all I flow packets can be network coded.

III. RESULTS AND DISCUSSIONS

In the following results, we set the contention window of access node equal to the contention window of terminal node.

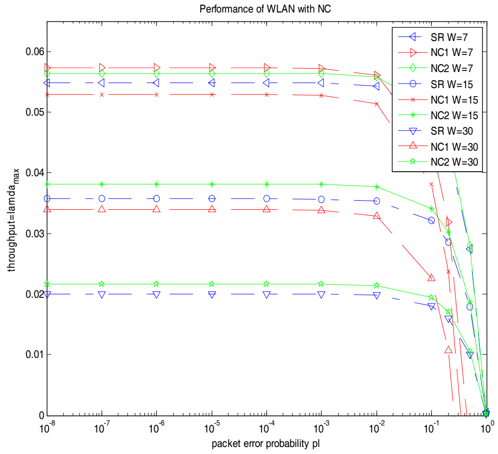

Fig. 3. Throughput V/s with packet error probability

Fig. (3) and (4) present the performance comparison for the scenarios of with Network coding (NC1 as in [9], NC2) and without network coding (SR).

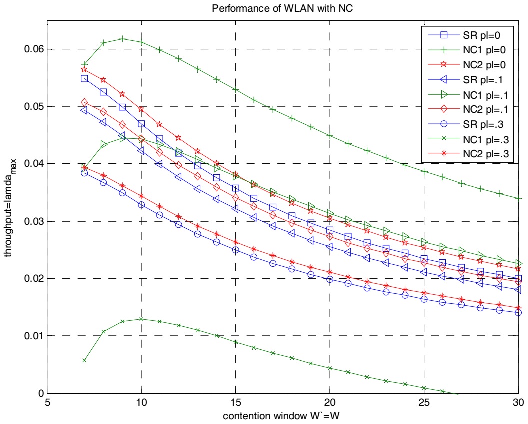

Fig. 4. Throughput V/s with contention window

Stable throughput v/s packet error probability is plotted for one value of contention window at a time. It can be seen that networks employing network coding, even in such scenarios with transmission error prone channels, exhibit better throughput than networks employing simple routing techniques (SR). From Fig. (3) we observe that the throughput with network coding rises by approximately 7% compared to simple routing when packet error probability is less than 10^{-2}.

IV. CONCLUSION

In this work we analyzed the throughput of WLAN in realistic scenarios where loss of packet in the network is not only due to collision but also owing to channel induced errors. Also, we take into account the feasibility of network coding at access node in accordance to the coding rule defined for COPE [3]. Thus use of Network coding exhibits better throughput than the networks employing simple store and forward routing techniques even in the presence of packet loss. From the analysis we observed that application of network coding to WLAN with one relay and six terminal nodes increases the throughput by 5 to 7% as compared to traditional store and forward routing.

V. APPENDIX

Equations (7) and (8) are arrived at as discussed in this appendix.

All the I flows that can be paired with the I flows initiated from node 1 is summarized in Table II below. The pairing of I flows are classified into two service classes. Those pairs for which network coding is feasible corresponds to class 1 with the service rate for the resulting coded packet doubled as compared to store and forward routing. I flows at access node that cannot be paired with any other I flow corresponds to class 2 and are to be simply forwarded individually. The class 2 service is defined for the flows indicated by '≠'. The class 1 service is defined for the following three cases:

1) I flow 1- 4 can be xored with I flow 4-1 at access node and multicast to node 1 & 4. Where node 1 can decode packet from 4 as it knows its own transmitted packet. Same way node 4 can decode packet from node 1. Similarly arguments for pairs indicated by '↕' in Table 2 holds good.
2) I flow 1-3 can be xored with I flow 3-6 at access node and multicast to node 6 & 3. Where node 3 can decode packet from 1 as it knows its own transmitted packet and node 6 can decode packet from 3 assuming it can overhear packet from its neighboring node1. Similarly arguments for pairs indicated by 'Δ' in Table II holds good.
3) I flow 1-3 can be xored with I flow 2-6 at access node and multicast to node 6 & 3. Nodes 3 and 6 can decode packets assuming they overhear the packet from the neighboring nodes 2 and 1 respectively. Similarly arguments for pairs indicated by '◊' in Table II holds good.

TABLE II: PAIRING OF I FLOWS AT ACCESS NODE

		I-flows which can be paired with I flows coming from terminal node 1																	
		1-3	1-4	1-5	2-4	2-5	2-6	3-1	3-5	3-6	4-1	4-2	4-6	5-1	5-2	5-3	6-2	6-3	6-4
I-flows from node 1	1-3	≠	≠	≠	≠	≠	◊	↕	≠	Δ	Δ	◊	◊	≠	≠	≠	≠	≠	≠
	1-4	≠	≠	≠	≠	≠	≠	≠	≠	≠	Δ	◊	◊	↕	Δ	≠	◊	≠	≠
	1-5	≠	≠	≠	≠	≠	≠	Δ	≠	◊	↕	Δ	Δ	Δ	◊	≠	≠	≠	≠

At access node the probability of network coding feasibility from figure is given as $\left(\frac{19}{52}x\frac{1}{2}\right)$.

The arrival rate for class 1traffic

$$\alpha_{c1} = (19/108)\sum_{i=1}^{6} 3.\alpha_I.prob(recption\ of\ I\ flow\ at\ access\ node) \\ - \alpha_{c1}\, prob(unsuccessful\ delivery\ of\ coded\ packet\ at\ both\ ends)$$

$$\alpha_{c1} = \frac{(19/36)\lambda}{(1-P_t\rho)^3(1-pl)[2-(1-P_t\rho)^3(1-pl)} \tag{12}$$

Each coded packet may not be received successfully due to collision or channel errors by any one of the destination node and hence need to be multicast only to that node using traditional forwarding method until received successfully. Thus arrival rate of such traffic is given as

$$\alpha'_{c1} = \alpha_{c1}\, prob(delivery\ of\ coded\ packet\ at\ one\ node\ and \\ failure\ at\ another) \\ -\alpha'_{c1}\ prob(unsuccessful\ delivery \\ of\ retransmitted\ packet\ at\ that\ destination)$$

$$\alpha'_{c1} = \frac{(19/36)\lambda[1-(1-P_t\rho)^3(1-pl)]}{(1-P_t\rho)^3(1-pl)[2-(1-P_t\rho)^3(1-pl)]} \tag{13}$$

The arrival rate of class 2 traffic similarly can be computed as

$$\alpha_{c2} = \{(108-19)/108\}\sum_{i=1}^{6} 3.\alpha_I.prob(recption\ of\ I\ flow\ at\ access\ node) \\ - \alpha_{c2}\, prob(unsuccessful\ delivery\ of\ I\ flow)$$

$$\alpha_{c2} = \frac{(89/36)\lambda}{(1-P_t\rho)^3(1-pl)} \tag{14}$$

Thus overall traffic intensity at access node is given by $\rho'_{NC2} = \frac{\alpha_{c1}}{2\mu'} + \frac{\alpha'_{c1}}{\mu'} + \frac{\alpha_{c2}}{\mu'}$ which leads to equation 10. By using the constraint traffic intensity is always less than 1 for stability, the maximum throughput is nothing but packet generation rate is given by equation 11, obtained from equation 10.

REFERENCES

[1] C. Fragouli, J. Y. L. Boudec, and J. Widmer, "Network Coding: An Instant Primer," *LCA-REPORT*-2005-010.

[2] R. Ahlswede, N. Cai, S. Y. R. Li, and R. W. Yeung, "Network information flow," *IEEE Trans. Inform. Theory*, vol. IT-46, pp. 1204-1216, 2000.

[3] S. Y. R. Li, R. W. Yeung, and N. Cai, "Linear Network Coding," *IEEE, Trans. Information Theory*, vol. 49, pp. 371-381, 2003

[4] R. Koetter and M. Mdard "An Algebraic Approach to Network Coding," *IEEE/ACM, Trans. Networking*, vol. 11, pp. 782-795, October 2003

[5] S. Katti, H. Rah, D. Katabi, M. Medard, and J. Crowcroft, “XOR s in the air: practical wireless network coding,” *IEEE/ACM Trans. Networking*, vol. 16, no. 3, pp. 497-510, Jun. 2008.

[6] S. Deb, M. Eros, T. Ho, D. R. Karger, R. Koetter, D. S. Lun, M. Medard, and N. Ratnakar, "Network Coding for Wireless Applications."

[7] S. Katti, S. Gollakota, and D. Katabi, “Embracing Wireless Interference: Analog Network Coding,” *SIGCOMM’07*, Kyoto, Japan, August 27–31, 2007,

[8] S. Rayanchu et. Al, “Loss-Aware Network Coding for Unicast Wireless Sessions: Design, Implementation, and Performance Evaluation,” *SIGMETRICS’*08.

[9] M. B. Iraji, M. H. Amerimehr, and F. Ashtiani, “An Analytical Approach for Throughput Evaluation of Wireless Network Coding,” in *proc. IEEE ICC* 2009.

[10] S. Sengupta et Al, “Network Coding-Aware Routing in Wireless Networks,” in proc. *IEEE/ACM Tran. On Networking*, vol. 18, no. 4, pp. 1158-70, 2010.