

Adaptive coding aware routing Algorithm in wireless Mesh Networks with multiple QOS constraints (ACAR)

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Abstract -Network coding is becoming an emerging communication technology by means of providing performance improvement in terms of throughput and energy efficiency. As majority of coding aware routing schemes centers on maximizing the coding opportunities, In this paper we have to optimize the benefits of network coding in the opportunistic routing. We propose a Adaptive coding aware routing Algorithm (ACAR) to encode the packets in two different flows that will not have the intermediate nodes. F-ACAR Algorithm select the optimal and adaptive encoder node from any one of the distinct flow and S-ACAR select any node which will be the neighbouring of the forwarding nodes of two distinct flows based on the anypath cost, delay and bandwidth estimation metrics. Due to this estimation ACAR can able to identify the high throughput and high packet delivery paths. We implement the F-ACAR and S-ACAR protocol in NS2 and compared with High throughput coding Aware routing Algorithm (HCOR). Simulation results show that bandwidth constrained adaptive coding aware routing Algorithm provides higher throughput than other coding aware routing algorithm.

Keywords: Network coding, Wireless mesh networks, bandwidth, any path cost-aware routing.

1. Introduction

IEEE 802.11 multihop wireless mesh networks (WMN) [1,2] is a promising technology, seen as a promising potential for internet service providers(ISPs) and other end- users to deliver a consistent wireless broadband service access and a robust network at a rational cost. Wireless mesh networks having many advantages over wired networks. They can organize and configure themselves dynamically. i.e. establishment and maintenance of the network is done automatically by the mesh nodes. It gives numerous benefits for the end-uses. Service Coverage becomes dependable and network is robust. Deployment and maintenance of WMN is easy and economical. Routing metrics are very essential for calculation of the best quality path. It does so by capturing an accurately good quality link. Due to the presence of static nodes and common wireless medium in

WMNs designing a good routing metric is a challenging. To study the impact of a good routing metric design is a challenge for researchers [3]. Network coding is a technique that exploits the broadcast nature in wireless networks to provide throughput improvements. This idea is first proposed in [4] and later developed as a practical network protocol [5]. This paper presents COPE, a new forwarding architecture that substantially improves the throughput of wireless networks. COPE inserts a coding shim between the IP and MAC layers, which identifies coding opportunities and benefits from them by forwarding multiple packets in a single transmission. This work describes an “X” scenario, and it is mostly used to illustrate how network coding can reduce the number of transmissions and increases the throughput for a given task. As shown in Figure 1, a packet from A to D and a packet from C to B can be transmitted with a total of 3 transmissions instead of 4 transmissions (A→O and O→D for one packet transmission and C→O and O→B for another packet transmission) using network coding technique. They are as follows: one transmission from A to O, one transmission from C to O, and a broadcast of the XORed packet by O. A and B can obtain each other's packet by XOR-ing again with their own packet. This process takes 3 transmissions instead of 4. Saved transmissions can be used to send new data, increasing the wireless throughput .This “X” structure is the only applicable network structure for the COPE protocol, which is the major limitation of COPE.

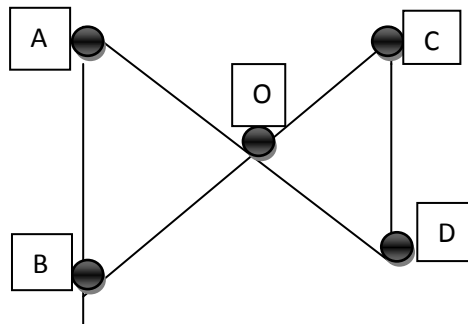


Figure 1. in “X” scenario, a packet from A to D and a packet from C to B can be transmitted with a total of 3 transmissions using network coding technique.

To overcome the restriction on coding-possible structures in static wireless networks, distributed coding aware routing protocol (DCAR) [6] was proposed which is applicable in all network topologies. With the general coding conditions defined, this protocol can discover coding possible routes in various kinds of network structures. In addition, DCAR proposed a coding-aware routing metric (CRM) to quantify and compare the merits between coding-possible and coding-impossible routes. DCAR based dynamic source routing (DSR) [7] protocol works in more general cases than the COPE based method. The coding opportunities are detected in the routing process. So more coding opportunities can be detected from ‘multiple’ coding structure. Free-ride oriented routing metric (FORM) [8] is a variation of DCAR and also works on multiple coding structure. Most of the above coding-aware routing schemes are focused on the deterministic routing protocols. Recently, network coding-aware opportunistic routing schemes were proposed to achieve more throughput in wireless networks [9-13]. Authors of CORE [9] proposed an NCOR method by combining hop-by-hop opportunistic forwarding and localized inter-flow network coding. Authors of [10] proposed a practical NCOR scheme for wireless mesh networks. Compared with NCOR schemes, high throughput coding aware opportunistic routing (HCOR) [14] considered the network coding cost in an opportunistic transmission and done a coding-aware opportunistic routing based on anypath cost. HCOR left wide open on the design of coding-aware opportunistic schemes to discover hidden coding opportunities that have been overlooked by other routing protocols. Therefore, we ought to consider the answer for the question of: whether the network coding is still benevolent for the transmission and how we take decision of the best choice of coding. Furthermore, the choice of determining the forwarding list and forwarding encoder node is also difficult when considering the network coding in order to gain of opportunistic transmission. To circumvent all these issues mentioned above, this paper focuses to address above issues using any path routing [14] with network coding and also estimate the available bandwidth [15] from source to destination to compute the gain of opportunistic transmission.

The remainder of this paper is organized as follows. Related works of network coding with various coding aware routing protocols are given in section 2. Section 3 is focused on the contribution of the paper. Section 4 gives some preliminaries for anypath cost and bandwidth calculation. ACAR algorithm is explained in section 5. Finally results and conclusions are given in section 6.

2. Related works

Various researchers emphasized on the issue of minimizing the number of relaying packets and incorporates heuristic algorithm to resolve this problem. Instead of optimizing the number of transmissions, COPE [16] considers the demand of fast forwarding into account and it executes a greedy encoding algorithm to identify whether the packets to different next hop can be encoded together or not. If the head packet is not able to encode with other packets in the forwarding buffer, relay node just forwards the local packet directly there by achieving higher throughput than conventional forwarding method. However, COPE depends on conventional routing method to set up the transmission path and nodes on path just passively detect coding opportunities among the received packets. Conventional routing method basically utilizes shortest path algorithm that leads to loss of coding opportunities. In COPE, a computational model was created to assess the throughput using network coding on multi-unicast sessions which finds forwarding route with maximal encoding opportunity in order to improve throughput. The distributed coding-aware routing system was proposed in DCAR [6] for wireless networks in which on-demand and link-state routing protocol were incorporated which utilizes the capability of coding opportunities into route selection with “Coding + Routing Discovery” and “Coding-aware Routing Metric” (CRM). To avoid “two-hop” limitation in COPE, DCAR adopts a more comprehensive coding technique by which substantial throughput is gained over COPE. In DCAR, the coding opportunities are detected in the routing process, so that more coding opportunities could be detected from ‘multiple’ coding constitution, however, the throughput is not increased always with the increase of coding opportunities in opportunistic transmission. The benefits of network coding in the opportunistic routing have been measured using high-throughput coding-aware opportunistic routing (HCOR) [14] to obtain the utmost throughput gain in wireless mesh networks. HCOR utilizes any path routing which considers network coding gain to discover the route with minimal any path cost fairly. It act as a serving layer by computing coding gain for sending and receiving of encoded packets and works between Internet Protocol (IP) and media access control (MAC). Network coding aware protocol developed by [17] utilizes potential coding opportunity for the discovery of route which verifies whether the current flow can be coded with authorized flows in networks and when multiple coding schemes available in some intervening node, the coding scheme with the maximum priority will be chosen. In addition it also uses link delivery ratio for the selection of optimal route by

adopting ETX metric ratio to compute and select the path that has the less transmission count. An opportunistic routing (OR) method was developed in [18] for wireless networks by which transmitted packet is overheard and coordinated among relaying nodes. Here, packets are forwarded by selecting any one the candidate node that has received the transmitted packet through the coordination among its candidate set. Because each node is allowed to construct its route to send the packet in OR method, transmission reliability and throughput could have been improved. In [19], random linear coded method for the data transmission in multi channel cognitive radio networks has been proposed for analyzing the performance of the two multi-channel automatic repeat requests (ARQ) based techniques. Distributed Greedy Coding-aware Deterministic Routing (DGCDR) has been presented by the authors in [20] to obtain the coding benefit for multi-flow in wireless networks in which decoding policy and coding condition were described in the multi-flow environment. This method utilizes the coding benefit of multiple intersecting flows under the greedy manner and additional confirmation process to test potential coding nodes. Furthermore, greedy aggregation and greedy coding algorithm has been incorporated for maximizing the coding node when multiple flows intersecting together. A unique interference aware routing protocol for wireless mesh network was proposed by Yuhuai et al in [21] by which paths are selected using interference cost thereby throughput capacity has been improved. It integrates the interference cost, topology information and traffic patterns so as to form routing metric and their performance has been evaluated by means of mean end-end throughput, delay, buffer overflow probability. For optimal encoding node selection we have to select node which should be in the forwarding list for sending an encoded packet. We introduce a method to estimate the available bandwidth of a multi-hop path with network coding. We measure the anypath cost and delay of network coding in an opportunistic transmission.

3. Conceptual view of ACAR:

When a new flow arrives to the wireless network, the source node of this new flow activates the *coding and routing discovery process* which has the following steps:

The source node s initiates the route discovery by broadcasting the Route Request (RREQ) message. The RREQ contains one hop neighbours and link qualities. This is to inform intermediate nodes to overhear information along the path. Upon receiving a RREQ, an intermediate node, first checks whether the RREQ has already

traversed through itself. If so, intermediate node discards the RREQ to prevent loop. Each node temporally stores RREQs during the discovery phase.

When a RREQ reaches the destination node, the destination replies with the Route Reply (RREP) message using the reverse path back to the source node. The RREP is a unicast message that contains the “path” information. Upon receiving a RREP, an intermediate node, compares the upstream path contained in the RREP with the paths in its temporally stored RREQs. If there is a match, then it has obtained both the “path” and “who-can overhear” information for the new path. Each node also maintains the “path” and “who-can-overhear” information for all the existing flows relayed by itself. If the two flows don’t have the intermediate nodes then the existing flows collect the overhear information of the other flow. If there any node have the same neighbouring nodes in their forwarder list, then we have to select that particular node as an intermediate node for two distinct flows. In ACAR, for selecting a high throughput path with more potential coding opportunities by introducing a coding aware routing metrics anypath cost, delay and bandwidth which jointly consider coding opportunities and related factors for comparing coding possible and coding impossible routes when multiple routes are available. Hence the metric used in ACAR is of great importance to the formulation of this paper. the terms used in this paper are listed in Table 1.

Table 1. List of terms used in this manuscript

Terms	Definitions
Encoded Packet	An XOR of multiple native (raw) packets
Forwarding list	Set of all new nodes for an intersect node on a flow for packet transmission
Coding node	A node that encodes raw packets together
Decoding node	A node which decodes encoded packets
Back warding list	Set of all existing nodes for an intersect node on a flow for packet transmission
Coding structure	Set of nodes and flows for opportunistic overhearing
Native packet	An raw or non-encoded packets

3.1 Flow-Adaptive code aware routing Algorithm (F-ACAR):

In network coding, the coding possible is applicable when two flows have the common intersecting node. If two flows don’t have the intersecting node but have the common overhearing node for any one of the flow, we can use F-ACAR

algorithm to do the network coding to reduce the number of transmission and increase the throughput. At first, the underlying assumptions used in this article are stated. A “coding node” is referred as a node which encodes packets such as node 2 or 3 or 6 or node 3 in Figure.2 and a “coding structure” is a collection of nodes and flows including the necessary transmitters for opportunistic overhearing, the coding node, the intended receivers which decode packets, and the necessary relaying nodes connecting the flows and the examples include all structures of figure 2. Coding structures is considered to be the basic building blocks for general networks which use the network coding paradigm. Throughout this paper, the interflow coding fashion is emphasized similar to the ones used in DCAR [6]. The central idea is to ensure that every encoded packet should be decoded by the respective receiver.

A. Necessary Coding Conditions

At first, necessary and sufficient conditions are stated so as to discover paths with potential coding opportunity with network coding. In this article, the following notations have been incorporated. Let s designate a node and $N(s)$ indicate the set of one-hop neighbors of node s and let F be a flow in which $s \in F$ to denote that node s is along the flow F . Let $F_{list}(s, F)$ represents the set of all forwarding nodes of node s in flow F , and $B_{list}(s, F)$ specifies set of all backwarding nodes of node s in flow F . For example in Figure.2, we have $F_{listA}(2, F_A) = \{1\}$, $F_{listA}(3, F_A) = \{1, 2\}$, $F_{listB}(6, F_B) = \{8, 7\}$, $F_{listB}(7, F_B) = \{8\}$, $B_{listA}(2, F_A) = \{3, 4\}$, $B_{listA}(3, F_A) = \{4\}$, $B_{listB}(6, F_B) = \{1\}$, $B_{listB}(7, F_B) = \{6, 1\}$. Generally, when two flows say F_A and F_B don't have intersect node, say node C , (nodes 2 and 6 in Figure.2), packets of these two flows can be encoded for transmission at node 2 and 6 *if and only if* the following coding conditions are met.

The definition of coding conditions is specified as follows:

Definition 1 (coding condition): coding conditions for two flows, say F_A and F_B , which have encoded node C , are:

- There exists if $(B_{listA}(C_A) \in N(F_{listB}(C_B)))$ where $B_{listA}(C_i)$ near to dst_A
- There exists if $(B_{listB}(C_i) \in N(F_{listA}(C_i)))$ where $B_{listB}(C_i)$ near to dst_k

Consider in figure 2. We have two flows A and B. Flow A is $1 \rightarrow 2 \rightarrow 3 \rightarrow 4$ and flow B is $8 \rightarrow 7 \rightarrow 6 \rightarrow 5$. In above flows don't have any intersection node for doing network coding. But flow A has the overhearing nodes (6 or 7) in flow B, at the same time flow B(2 or 3) has the overhearing nodes list in flow A. With the arrival of a new flow B, new

coding opportunities are introduced at node 6 and 7. These two nodes can sense this new opportunity as an intermediate node.

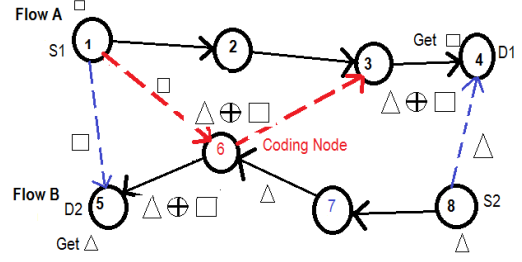


Figure 2. Network coding of two neighbouring flows without having the intermediate node

Without the knowledge of forwarders and backwards list of two flows. Flow A will not be aware of the flow arrival B and also not to mention changing the route to utilize this coding opportunity. In F-ACAR protocol flow A change the route via $1 \rightarrow 6 \rightarrow 3 \rightarrow 4$ or $1 \rightarrow 2 \rightarrow 7 \rightarrow 4$ based on the optimal encoder node and fully utilizing the coding opportunity. Without network coding to transmit the packets from node 1 to 4 we required 3 transmissions ($1 \rightarrow 2 \rightarrow 3 \rightarrow 4$), at the same time to transmit the packets from node 8 to 5, we required 3 transmission ($8 \rightarrow 7 \rightarrow 6 \rightarrow 5$), so totally 6 transmission required for flow A and B. using network coding, if we select node 6 as a encoded node, then the transmission will be $1 \rightarrow 6 \rightarrow 3 \rightarrow 4$ and $8 \rightarrow 7 \rightarrow 6 \rightarrow 5$. Here the encoded node 6 XORed and broadcast the packets from a node 1 from flow A and 7 from flow B, so that only 5 transmissions required instead of 6 transmissions.

3.2 Selective flow- Adaptive code aware routing Algorithm (S-ACAR) :

If we have two flows don't have the common intersecting node or common overhearing node in the forwarders and backwards list of any one flow, then we select S-ACAR algorithm to do the network coding. S-ACAR algorithm is applicable only when two flows have common overhearing node in the network then we have to select any one of the optimal node which should be placed in neighbour list of two flows and also satisfy the coding condition i.e destination of flow A should be listed in forwarder list of flow B and destination of flow B should be listed in forwarder list of flow A.

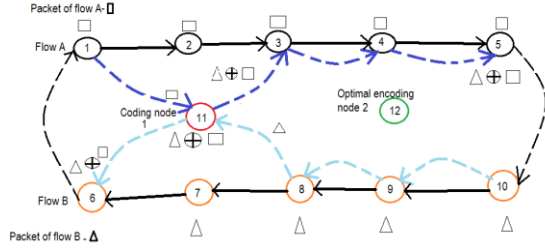


Figure 3. Network coding of two different flows not having the intermediate node and not having the common neighbouring node in any one flow

For the above example in figure 3, take two distinct flows, flow A need 4 transmission to deliver the packet from node 1 to 5 ($1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5$) at the same time flow B required 4 transmissions to deliver the packet from node 10 to 6 ($10 \rightarrow 9 \rightarrow 8 \rightarrow 7 \rightarrow 6$). So totally 8 transmissions required for two flows. In figure 3, consider node 11 and node 12, both nodes are common opportunistic node of two flows A and B. using node 11, flow A and flow B reroute the routing procedure via $1 \rightarrow 11 \rightarrow 3 \rightarrow 4 \rightarrow 5$ and $10 \rightarrow 9 \rightarrow 8 \rightarrow 11 \rightarrow 6$. In this node 11 XORed and broadcast the packets from node 1 and 8. Because of that we have to reduce three transmissions instead of four transmissions. The reduction of transmission time of both flows can increase the throughput. Using the optimal encoder selection algorithm, we have to select another route for flow A $1 \rightarrow 2 \rightarrow 3 \rightarrow 12 \rightarrow 5$ and for flow B $10 \rightarrow 12 \rightarrow 8 \rightarrow 7 \rightarrow 6$. To utilize the coding opportunity we have to phase severe problems based on the reroute procedure. The first is discovering of new flows and new coding opportunities. The second one is evaluation of these coding opportunities and take decision of changing the existing routes. To complete the procedure, we also do a third step to test whether the newly introduced complexity is well compensated with high performance.

4. Calculations of Route metrics

4.1 Anypath Cost

In classic wireless network routing, each node forwards a packet to a single next hop. As a result, if the transmission to that next hop fails, the node needs to retransmit the packet even though other neighbours may have overheard it. In contrast, in anypath routing, each node broadcasts a packet to multiple next hops simultaneously. Therefore, if the transmission to one neighbour fails, an alternative neighbour who received the packet can forward it on. This set of multiple next hops is defined as the forwarding set and J to represent it throughout the paper. A different forwarding set is used to reach each destination, in

the same way a distinct next hop is used for each destination in classic routing. When a packet is broadcast to the forwarding set, more than one node may receive the same packet. To avoid unnecessary duplicate forwarding, only one of these nodes should forward the packet on. For this purpose, each node in the set has a priority in relaying the received packet. A node forwards a packet only if all higher priority nodes in the set failed to do so. Higher priorities are assigned to nodes with shorter distances to the destination. As a result, if the node with the shortest distance in the forwarding set successfully received the packet, it forwards the packet to the destination while others suppress their transmission. Otherwise, the node with the second shortest distance forwards the packet, and so on [22,23]. The source keeps rebroadcasting the packet until someone in the forwarding set receives it or a threshold is reached. Once a neighbour in the set receives the packet, this neighbour repeats the same procedure until the packet is delivered to the destination. We now use a set of next hops to forward packets; every two nodes will be connected through a mesh composed of the union of multiple paths. Figure 1 depicts this scenario where each node uses a set of neighbors to forward packets. The forwarding sets are defined by the multiple bold arrows leaving each node. We define this union of paths between two nodes as an anypath. In the figure, the anypath shown in bold is composed by the union of 11 different paths between a source S and a destination D . Depending on the choice of each forwarding set, different paths are included in or excluded from the anypath. At every hop, only a single node of the set forwards the packet on. Consequently, every packet from S traverses only one of the available paths to reach D . We show the path possibly taken by a packet using the dashed line. Succeeding packets, however, may take completely different paths; hence the name anypath. The path taken is determined on-the-fly, depending on which nodes of the forwarding sets successfully receive the packet at each hop.

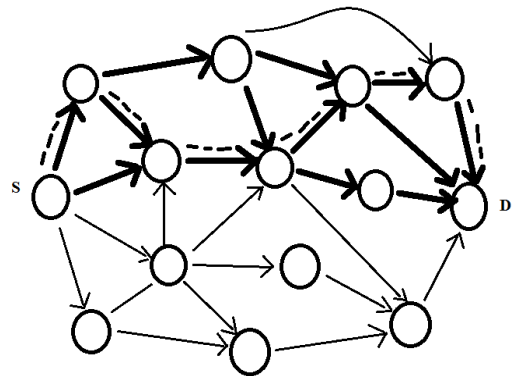


Figure 4. Any path connecting nodes S and D

Anypath is composed of the union of 11 paths between the two nodes S and D in figure 4 using bold arrows. Every packet sent from S traverses one of these paths to reach D. Different packets may traverse different paths, depending on which nodes receive the forwarded packet at each hop with higher priority named as anypath is shown in dashed line in figure 4.

In order to support the point-to-multipoint links used in anypath routing (Figure 5), the wireless mesh network represented as a hypergraph $G=(V,E)$, where V is the set of nodes, and E is the set of hyperlinks, each hyperlink being an ordered pair (i,J) , where i is a given node connected with the forwarding set J of neighboring node. The cost of anypath from a given node i to the destination D via a forwarding set J defined using Bellman equation:

$$C_i = C_{iJ} + C_J \quad (4.1)$$

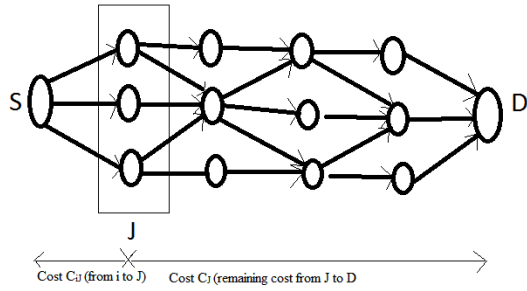


Figure 5. Scheme of anypath cost calculation

This is composed of the broadcast cost C_{iJ} from i to J and the remaining-anypath cost C_J from J to the destination. Assuming independent packet losses, C_{iJ} can be defined as:

$$C_{iJ} = \frac{1}{d_{iJ}} = \frac{1}{1 - \prod_{j \in J} (1 - d_{ij})} \quad (4.2)$$

Where d_{iJ} is the probability of packet delivery from node i to at least one node from J based on individual probabilities of packet delivery d_{ij} for links (i, j) . C_{iJ} value represent the expected number of anypath transmission needed to successfully deliver the packet sent by node i to any node from J . The remaining cost C_J is defined as the weighted average of the costs of all paths from J to D ,

$$C_J = \sum_{j \in J} w_{ij} C_j, \text{ with } \sum_{j \in J} w_j = 1 \quad (4.3)$$

Where C_j is the cost of a path between a node j from J and the destination node D , while weight w_{ij} in (4.3) denotes probability of node j being the forwarding node of a packet received from node i . The weight w_{ij} is then defined as

$$w_{ij} = \frac{d_{ij} \prod_{k=1}^{j-1} (1 - d_{ik})}{1 - \prod_{j \in J} (1 - d_{ij})} \quad (4.4)$$

Among all possible paths, the anypath is selected based on the shortest ETX (Expected Transmission Count). In any path routing, an intermediate node receives a packet from a flow only when the destination and neighbours should be in the downstream of this flow. According to the coding condition,³ the potential decoding nodes of this packet should be either in destination or in one hop before the destination. [24-28].

4.2 Delay

Delay is the difference between the time at which the sender generated the packet and the time at which the receiver received the packet.

$$\text{Total Delay}(D_i) = \text{Receiving time of packet } (i) - \text{Sending time of packet } (i) \quad (4.5)$$

4.3 Bandwidth Estimation

Bandwidth Estimation is important consideration in QoS-aware routing which is used for supporting real-time video or audio transmission. To support bandwidth-guaranteed QoS, the available bandwidth from source to the destination should be known. Each node estimated its consumed bandwidth by tracking the packets transmitted through the network. This value is recorded in the bandwidth consumption register of the node and updated periodically.

Hello Bandwidth Estimation: In the “Hello” bandwidth estimation method, the sender’s current bandwidth usage as well as the sender’s one-hop neighbours’ current bandwidth usage is piggybacked onto the standard “Hello” message. Each host estimates its available bandwidth based on the information provided in the “Hello” messages and knowledge of the frequency reuse pattern. This approach avoids creating extra control messages by using the “Hello” messages to disseminate the bandwidth information.

ID	Consumed Bandwidth	Timestamp
Neighbor ID 1	Consumed Bandwidth	Timestamp
.	.	.
.	.	.
.	.	.
Neighbor ID n	Consumed Bandwidth	Timestamp

Figure 6. Hello Structure

ACAR uses the “Hello” messages to update the neighbour caches. The “Hello” message keeps the address of the host who initiates this message. We modify the “Hello” message to include two fields. The first field includes host address, consumed bandwidth, timestamp, and the second field includes neighbours’ addresses, consumed bandwidth, timestamp, as shown in Figure. 6. Each host determines its consumed bandwidth by monitoring the packets it feeds into the network. This value is recorded in a bandwidth-consumption register at the host and is updated periodically.

$$B_{wij} = \frac{1}{1 - \prod_{j \in J} (b_{wij})} \quad (4.6)$$

b_{wij} is a consumed bandwidth for the transmission from i to j .

5. Coding procedure and coding feedback

Whenever a node i receive a new packet p_k from flow f_k , it executes the coding procedure illustrated in Algorithm 1.

Algorithm 1 - Adaptive Optimal Encoder coding condition:

F_j, F_k - Input flow list
 $Flist_j, Flist_k$ - Collection of forwarder list of each node in the flow F_j and F_k
 $Blist_j, Blist_k$ - Collection of backwarder list of each node in the flow F_j and F_k
 CN_{jk} - list of common node of flow F_j and F_k
 dst_j, dst_k - destination node of flow j and k
Input : $F_j, F_k, Flist_j, Flist_k, Blist_j, Blist_k, CN_{jk}, dst_j, dst_k$,
if $(F_j == \Phi \ \& \ F_k == \Phi)$ then
return “No Route”
else if (common node CN_{jk} is not empty)
select algorithm 2
else
No common node for flow F_j & F_k
 f_j - any node in flow F_j
 f_k - any node in flow F_k
if $(f_j \in F_j \text{ is a neighbor of } f_k \in F_k)$
{ pick f_j as a common node and put into the CN_{jk}
select algorithm 2
}
else if $(f_k \in F_k \text{ is a neighbor of } f_j \in F_j)$
{
pick f_k as common node and put into the CN_{jk}
select algorithm 2
}
else
{
for each node $n \in N; n \notin F_j \ \& \ n \notin F_k$

```
{
  if (n is a neighbor of  $f_j \in F_j$  &&
      n is a neighbor of backward list of  $(f_j)$  && n
      is a neighbor of forward list  $(f_j)$  &&
      n is a neighbor of  $f_k \in F_k$  &&
      n is a neighbor of  $Blist_k(f_k)$  &&
      n is a neighbor of  $Flist_k$ )
  {
    put n into  $CN_{jk}$ 
  }
  select algorithm 2
}end
}end
}end
if  $CN_{jk}$  is empty
  return N -route
else
  return Success
endif
```

Algorithm 2 for optimal Encoder selection:

Input : $F_j, F_k, Flist_j, Flist_k, Blist_j, Blist_k, dst_j, dst_k$
Common node $(F_j, F_k) \rightarrow CN_{jk}$
If (coding possible (i))
{
(i) Estimate cost C_i using equation (4.1)
(ii) Estimate delay D_i using equation (4.5)
(iii) Estimate bandwidth BW_i using equation (4.6)
}
for each node ‘i’ in coding possible list
calculate $T_j = (W_1 C_i + W_2 D_i + W_3 BW_i)$
find max $(T_j) \rightarrow T_k \rightarrow k$ is optimal node
end
end

Algorithm for coding possible node C_i :

Coding $j = 0$;
Coding $k = 0$;
if $(Blist_j(C_i) \in N(Flist_k(C_i)))$ where
 $Blist_j(C_i)$ near to dst_j ;
decoding $j = Blist_j(C_i)$;
 $O_j = N(Flist_k(C_i))$;
Coding $j = 1$;
End
if $(Blist_k(C_i) \in N(Flist_j(C_i)))$ where $Blist_k(C_i)$ near to
 dst_k ;
decoding $k = Blist_k(C_i)$;
 $O_k = N(Flist_j(C_i))$;
Coding $k = 1$;
End
return(Coding $j \oplus$ Coding k);
end

Decoding

In ACAR, every node works in the promiscuous mode and stores all overheard packets in its Packet Pool. The encoded packet can be decoded using XOR method such as $p1 = (p1 \oplus p2) \oplus p2$.

6. Experiment results

We evaluated the performance of F-ACAR and S-ACAR by comparing with HCOR coding scheme using NS2 Simulator. We construct 100 node random topologies with size $1,000 \times 1,000$. The Network coding HCOR which is a kind of coding opportunity-aware routing method and runs on a multihop coding structure. HCOR does the network coding whenever a coding opportunity happens and select the first node among the coding nodes, while F-ACAR and S-ACAR do not select the first coding node from the coding opportunity, it selects the node which has more gain and minimum delay among the coding nodes. In our simulations, all the nodes are set to the promiscuous mode with a modified IEEE 802.11 standard MAC protocol which supports the opportunistic transmission. We use User Datagram Protocol (UDP) traffic sources, and all the flows are constant bit rate (CBR), with a fixed packet size of 512 bytes. The transmission range is set to 250 m, and the interference range is set to 550 m with Two Ray Ground propagation model.

Using anypath routing, each packet is broadcasted to a forwarding set composed of several neighbouring nodes and the packet should be retransmitted only if none of the neighbours in the set receive it. Therefore the link to a given neighbour is down or performing poorly, another nearby neighbour receives the packet and forwards it on. In our ACAR routing algorithm we calculate anypath cost, delay and also estimate the available bandwidth of coding nodes and routing paths. Because of that we can select the optimal encoder node for packet transmission. In figure 2 and figure 3, two flows do not have the intermediate nodes, so that we cannot do the network coding for that routing flows. Using OES algorithm, we have done the network coding for two flows which don't have the intermediate nodes and also select the encoding node among all the possible coding nodes within two hops from the first coding node. Number of transmissions for two distinct flows can be reduced by network coding. Reduction in number of transmission increase the network throughput compared to HCOR routing algorithm shown in figure 7 & 8.

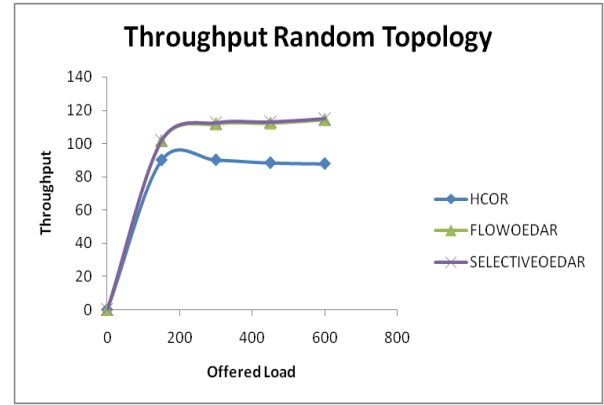


Figure 7. Overall resultant Throughput Vs Load performance for random topology

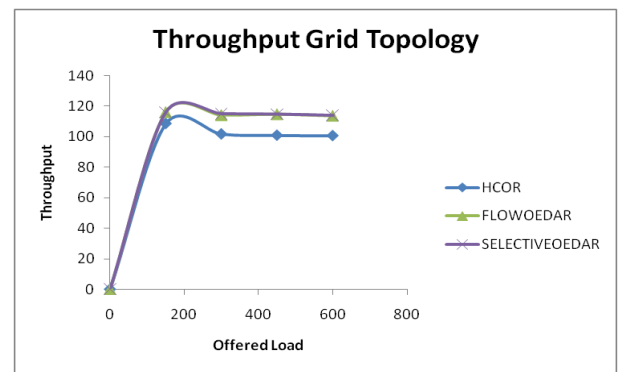


Figure 8. Overall resultant Throughput Vs Load performance for grid topology.

In our algorithm, we select the path which has minimum delay and minimal anypath cost. The above factors increase the 15% of packet delivery ratio which reduce the 10% of delay in the network compared to HCOR routing algorithm shown in figure 9, 10, 11 and 12.

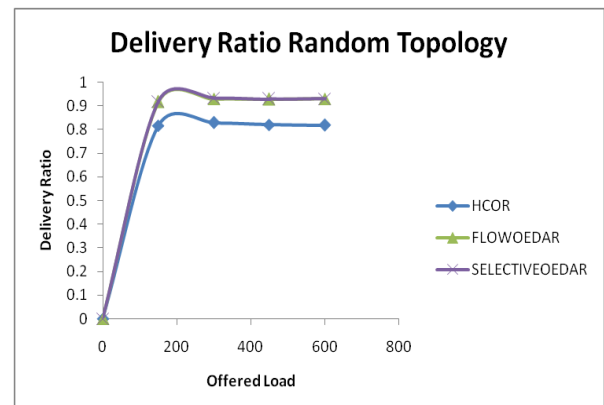


Figure 9. Overall resultant Packet delivery ratio Vs Load performance for random topology.

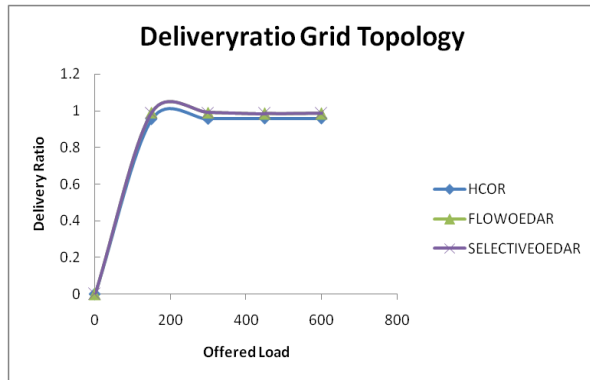


Figure 10. Overall resultant Packet delivery ratio Vs Load performance for grid topology

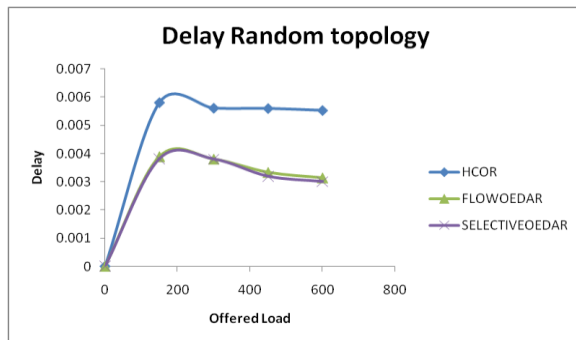


Figure 11. Overall resultant Delay Vs Load performance for random topology

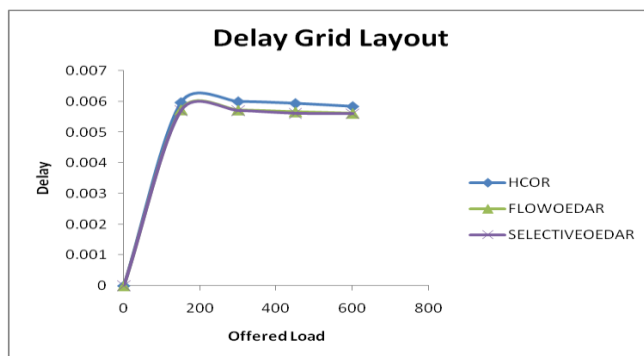


Figure 12. Overall resultant Delay Vs Load performance for Grid topology.

7. Conclusion

We propose an Adaptive Coding Aware Routing Algorithm (ACAR) which is optimal encoding node selection algorithm in network coding for wireless mesh networks. This routing algorithm incorporates potential coding opportunities into route selection using the "Optimal Encoder Selection algorithm". ACAR also adopts a more generalized coding scheme by eliminating the "two-hop" limitation in COPE [16]. Taking advantage of Optimal Encoder Selection Algorithm, we give a computing method to calculate network coding cost, bandwidth estimation and delay in opportunistic transmission.

We implement the ACAR scheme in ns-2 and carry out extensive simulations reveal substantial throughput gain over HCOR. Our future work is to design of coding-aware opportunistic schemes with encoding of more than two native flows together.

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