Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2016) 24: 1235 – 1247

doi:10.3906/elk-1308-73

An enhanced multiinterface multichannel algorithm for high quality live video streaming over hybrid WMNs

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Received: 13.08.2013 • **Accepted/Published Online:** 25.02.2014 • **Final Version:** 23.03.2016

Abstract: Recently, providing live video streaming over hybrid wireless mesh networks (WMNs) has been of great interest. In this kind of network, most of the users usually move with low speed and always keep their connections within the network by attaching to different mesh routers (MRs). When evaluating a mesh technology, it is important to pay special attention to this kind of device as it is mostly handled by the final user. These devices, known as STA nodes, neither run a routing protocol nor perform forwarding operations. Although our proposed distributed locator service in GREENIE makes hybrid WMNs more efficient for supporting STA nodes, video distortion increases when the number of them sharply augments. In order to address this problem, we equip MRs with an efficient multiinterface multichannel (MIMC) algorithm. The proposed algorithm is an engineering solution that completely considers the channel status and its queue length. Moreover, it is cost effective and simple in its implementation without imposing unnecessary complexity on the network. Simulation results using OMNET++ show that all the tested routing protocols, and GREENIE in particular, efficiently exploit the advantages of the designed MIMC algorithm by improving the video distortion, total capacity of successfully received video packets, number of successfully received video frames, packet delay variation, and end-to-end delay metrics. As a result, better video quality can be provided on STA nodes.

Key words: Multiinterface multichannel, hybrid wireless mesh networks, live video, performance evaluation

1. Introduction

Focusing on commercial implementations, wireless mesh networks (WMNs) are introduced as a key wireless technology with considerable attractions for users and application developers [1]. As a type of mesh-based network, a WMN can be defined as a hybrid network including a mix of mobile and fixed nodes. Due to the wireless links and the autoconfiguration capabilities of the WMNs, there is no need to pay high costs for an expensive infrastructure in order to cover a wide area. Since live video streaming over WMNs has been of great interest [2], the necessity of employing an efficient routing protocol for providing smooth video playback on wireless nodes is inevitable. This protocol should address some important challenges such as interferences and node mobility. Recently, proactive (e.g., open link-state routing protocol (OLSR) [3]), reactive (e.g., ad hoc

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on-demand routing protocol (AODV) [4]), and spanning tree [5] routing protocols have been employed in many previous studies and real implemented WMNs.

Our previous research, GREENIE [6], shows that an efficient hybrid routing protocol can noticeably reduce the effects of these challenges on the perceived video quality. GREENIE intelligently exploits the advantages of proactive and reactive routing protocols in which mesh routers (MRs) employ both approaches. Particularly, mobile mesh nodes use the reactive mode, whereas the static mesh nodes are able to execute both. The static mesh nodes promote the use of the most stable links, that is, those between static elements. Thus, GREENIE always finds the most stable path irrespective of whether a gateway is part of the path or not.

It is necessary to point out that there are four different nodes in a WMN. Mesh nodes support all network layers and can move freely. Mesh routers can include access point capabilities and support routing as well as forwarding. Alternatively, mesh repeaters can only support routing and forwarding in the link layer. Both mesh routers and repeaters are usually static. Finally, there is another type of node, named STA, which has a low mobility speed. These nodes do not support routing and forwarding and always connect to an MR, because they operate in an infrastructure mode. The fact is that STA nodes constitute a large fraction of nodes in a real hybrid WMN. GREENIE shows that it can support these nodes better than other routing protocols. In other words, using the proposed distributed locator service in [6], all protocols, specifically GREENIE, support STA node more efficiently.

However, the performances of the routing protocols significantly degrade when the number of STA nodes increases. In order to cope with this problem, this paper presents an efficient multiinterface multichannel (MIMC) algorithm. The proposed MIMC algorithm is a cost effective engineering solution that lets routing protocols provide higher video quality on wireless nodes even if the number of STA nodes increases. In particular, the proposed MIMC algorithm takes into account the channel status and its queue length when performing the channel assignment. The main goal of this operation is to reduce the end-to-end delay as well as the interferences on the wireless medium.

MRMI (mesh router with MIMC capability) refers to those MRs that are equipped with the MIMC feature in the rest of this paper. MRs can be equipped with the MIMC algorithm independently of the routing protocols supporting the wireless mesh network.

This study compares the performance of GREENIE with other routing protocols when they exploit the advantage of our MIMC algorithm. The proposed algorithm effectively considers both the status and the queue size of an interface, which can result in better load balancing among different interfaces. The results show that GREENIE provides the highest performance in comparison with other routing protocols when MRMIs are used in the network. This study compares the performance of these protocols in terms of the total number of received frames and bytes, video distortion, end-to-end delay, and packet delay variation based on the two scenarios. There is no MRMI in the first scenario, whereas MRs are equipped with MIMC capability in the second one.

Altogether, the main purposes of this research are as follows:

i. To propose an efficient engineering multiinterface multichannel solution that is cost effective and simple in its implementation without imposing unnecessary complexity on the network. This is very important for some delay-sensitive traffic such as live video streaming, because the network does not experience an additional delay for the channel assignment process.

ii. To show how different routing protocols can exploit its advantages in a delay sensitive data stream such as live video. Live video streaming introduces more challenges than file sharing and on-demand video streaming do. Therefore, the real efficiency of an algorithm, which can affect the performance of a network, can be precisely and comprehensively evaluated when a live video stream is disseminated in the network.

iii. To show how GREENIE, proposed in our previous study, exploits the advantages of the proposed multiinterface multichannel algorithm more efficiently. The obtained results clearly justify our assertion: GREENIE effectively uses the backbone of a hybrid WMN in order to efficiently route the packets.

The rest of this paper is organized as follows. An introduction to MIMC and some important related works are presented in Section 2. The problem statement is discussed in Section 3. Section 4 introduces the proposed MIMC algorithm. Simulation results are discussed in Section 5 and the paper is concluded in Section 6.

2. Related work

The multihopping technique increases the network scalability, but it is associated with a higher level of interferences. In fact, the capacity reduction is a well-known issue derived by the interference problem in multihop wireless mesh networks [7]. This problem can be mitigated using a multiinterface multichannel technique [8]. In fact, as the current price of network interface cards (NICs) has quickly dropped, the existing standards such as IEEE 802.11 a/b/g opt for multiple nonoverlapping channels. In this regard, a mesh node equipped with more than one interface can concurrently communicate with other nodes on different channels. This operation results in less interferences in the network.

In order to assign the channels to the interfaces, it is necessary to decide on the convenience of the assignation by means of metrics. There are three methods for channel allocation: static, dynamic, and hybrid [7]. Using the static method, each channel can be either permanently or for a specific long period of time assigned to a specific interface. Moreover, it is possible to either assign the same channel set to the same interface (e.g., channel 0 to interface 1 in all nodes) or different channel sets to the different interfaces in every node [9]. This research calls these two methods Static-type1 and Static-type2, respectively. The second type may increase the number of hops on the path between a source and a destination. As another challenge, the network may be partitioned into at least two sections. The most important advantages of the static channel assignment method are better control over the network topology, very low imposed complexity, and overhead on the networks as well as no need for coordination among nodes. As a result, it seems to be an adequate technique for live video streaming over WMNs.

On the other hand, any channel can be assigned to any interface using a dynamic method. It means that an interface can periodically switch among different available channels. Switching can occur very frequently [10] or rarely [11]. The advantage of this method is that it is possible to cover many channels with few interfaces. However, switching imposes high delay and overhead, which are not suitable for delay sensitive streaming (e.g., live video). In addition, it is necessary to employ a coordination mechanism among the nodes (e.g., rendezvous [12]), because the two interfaces in two neighbors may be assigned to different channels. Finally, an efficient decision method for switching time is required. As a result, the dynamic method seems to be an inefficient method for live video streaming. Finally, using a hybrid method, some nodes employ a static channel assignment while others opt for a dynamic approach. Moreover, it is possible that one interface uses the dynamic assignation, while others use a static channel assignment approach [7]. As an example, HMCP is a hybrid method that exploits both static and dynamic channels [13]. Although recent studies such as [14] and [15] show that hybrid approaches exploit the advantages of both static and dynamic methods, they introduce two main problems. Firstly, it is necessary to have an intelligent integration algorithm. In other words, an inefficient integration of the two basic methods does not only impose high costs on the network, but it also provides a lower performance than that resulting from applying just one method. Secondly, battery energy source is an important open issue in mesh and STA nodes in which it is impossible to run complex hybrid methods on them.

First studies such as (www.soi.wide.ad.jp/class/20040013/slides/09) analyzed the effect of interferences on partially overlapping channels and on the same channels [16]. Recent studies have introduced different MIMC algorithms. A multiinterface routing protocol (MIRP) is proposed in [17] and evaluated over the TJU MeshNet testbed. In the performed study, the effects of bandwidth, interferences, number of available channels in each node, number of gateways, and MRs are examined on the network throughput when no MR or gateway generates traffic. The number of channels in each MR equals to the number of interfaces, because it can maximize the network capacity. The results show that MIRP improves the network performance. A learning mechanism is proposed in which nodes can autonomously learn how to assign channels to their interfaces based on the existing information about channel usage in their neighborhood [11]. A location-aware routing metric (ALARM) is introduced in [18] to efficiently capture the level of cochannel interferences.

A routing optimization and a link layer scheduling method is proposed in [19]. MIND is another interference-aware routing metric that passively monitors interferences and load in a WMN [20]. As another solution, HOVER [21] employs ETX metric for selecting the best interface, which introduces some important issues. First of all, gathering enough information for calculating ETX imposes high network overhead. Secondly, ETX cannot take the actual status of the network, because it is a mean value. In addition, ETX cannot reflect the network condition quickly in highly dynamic networks. As a specific problem with HOVER, it does not consider the queue size of the different interfaces. All in all, using any routing metric for finding the best output interface introduces the same problems as ETX. In order to increase the network performance, the first channel assignment algorithm (FRCA), a static-type1 approach, is proposed for efficiently utilizing multiinterfaces in the network [8]. In contrast to the load-aware channel assignment algorithm (LACA) [9], which considers each link in decreasing order of the estimated traffic for assigning a channel to its related interface, FRCA first randomly assigns channels to different interfaces. Then, based on the results of the first phase, it performs a heuristic method for channel assignment. Although FRCA exploits the advantages of a static channel assignment method, it imposes high costs due to running two independent phases for performing a heuristic channel assignment method.

What can be inferred from some of these studies is that they considered an arbitrary number of orthogonal (nonoverlapping) channels. However, we think that it is not a practical, cost effective engineering solution. The first reason is that the IEEE 802.11g standard only has four orthogonal channels. If we consider the first channel for the communication between access points (APs) and STAs, and the second channel for common communication with nonmultiinterface nodes, there are only two free channels available. This is completely in conflict with the assumptions of previous works, based on an arbitrary number of orthogonal channels. A reason to conclude that previous solutions are inadequate is the following one: suppose that a node moves in the network or the traffic characteristics change. In these cases, it is necessary to compute a new distribution channel map and propagate it in the network, which is a complex task. This complexity will be more evident if there is a high level of interferences from other networks. Complex channel assignment algorithms need a more powerful CPU.

3. Problem statement

This section briefly classifies those challenges in efficient live video streaming over hybrid WMNs, which can be addressed using an efficient MIMC algorithm. These challenges are as follows:

i. The number of mobile devices accessing the network services is expected to be increased. This can augment the interferences experienced on the wireless channels. Collisions and interferences significantly reduce the capacity of a wireless mesh network, which results in a low network performance and an unsatisfactory video quality.

ii. Some traffic applications such as live video streaming are delay sensitive and require large bandwidth. Using the most recently used video encoding standard, the H.264/MPEG-4 [22], there are decoding dependencies among video frames. To illustrate this problem, consider the group of pictures (GoP) in Figure 1. Each frame P can be successfully decoded if the previous frame I is successfully received and decoded, while decoding a frame B depends on the successful decoding of the previous and the following frames I and P. Suppose that frame P1 is not received while frames B1 and B2 are received and stored in the local buffer. Because of the decoding dependency, the video player cannot playback frames B1 and B2, which leads to a higher video distortion.

iii. GREENIE, in contrast to other routing protocols, can efficiently support STA nodes using the distributed locator service designed in [6]. However, the performance of all routing protocols can be affected when the number of these nodes sharply increases. Although the locator service efficiently helps mesh nodes and routers to locate the positions of STA nodes, interferences sharply augment when the number of STA nodes also increases.

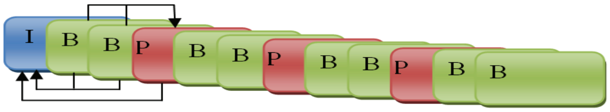


Figure 1. A GoP consists of twelve frames (G12B2).

In order to cope with these challenges, the next section introduces a simple but efficient MIMC algorithm. Taking into account the fact that we want to provide a high-quality live video, the MIMC algorithm should try to avoid the delays associated with channel status. In addition, the energy consumption should also be reduced. Thus, the requirements that an efficient MIMC algorithm should fulfill are as follows:

i. In contrast to previous studies, it does not impose unnecessary complexity on the network and it also permits routing protocols to provide considerable improvement in their performance, especially when a delay sensitive stream is disseminated in the network,

ii. It considers the state of channels. In this regard, IDLE channels have higher priorities than busy channels. Efficient load balancing is the most important goal and so the states of the channels should be considered in a MIMC algorithm,

iii. It considers the queue lengths of the different channels. This not only improves the load balancing on the different channels, but it also decreases the end-to-end delay, which is very important in live video streaming over WMNs.

iv. This algorithm should be simple and cost effective in its implementation. In this regard, it should be easily developed for a real WMN with low implementation cost.

4. The proposed MIMC algorithm

In contrast to the studies discussed in Section 2, the proposed engineering solution is simple to be implemented and cost effective. We assume that the technology used is IEEE 802.11g. Considering three wireless interfaces for each node in the backbone, they always have access to all available orthogonal frequencies. Therefore, it is possible to avoid the use of complex algorithms for distributing the frequencies among nodes. Using this solution, each multiinterface node can locally decide for the next hop of a received packet (the best channel) without the necessity of synchronizing different channels among different nodes. In this regard, the performance of the network can be considerably improved.

The basis of our proposal is that different interfaces of a node, which share the same link address and can work at different orthogonal frequencies, are like a logical interface in the upper layers as depicted in Figure 2. Actually, in our proposed algorithm, a link layer can have multiples MAC sublayers in the same link layer module, in which all of them are connected to the same management sublayer.

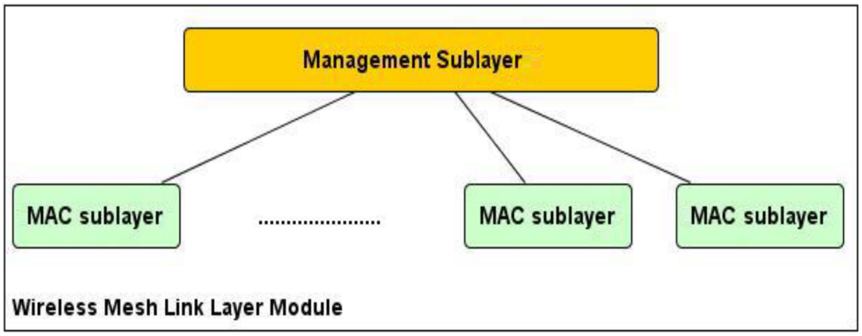


Figure 2. The designed multiinterface feature.

Using the same MAC address for different sublayers in a node, the process of searching for a node is simplified: now the node does not have multiple MAC addresses attached to the same wireless mesh node. We suggest that the multiinterface feature is supported on those nodes that have sufficient battery resources. Therefore, this study supposes that only the nodes in the backbone (MRs) are equipped with this functionally.

Although this seems to be a limitation, it is perfectly adapted with GREENIE, because it is oriented to maximize the use of the backbone nodes, especially MRMIs. Using the proposed feature, every multiinterface node simultaneously broadcasts the routing information messages associated with all its interfaces. In this regard, every node learns how many interfaces at the same channels are shared with its neighbors. In this case, the proactive routing protocol lets each node know which of its interfaces is connected to which of another neighbor's interface.

Some MRMIs have AP capabilities. This research calls them MRMIAP. Therefore,

i. Each MRMI has three interfaces, 0, 1, and 2, permanently assigned to channels 0, 2, and 3, respectively. This is a static channel assignment method.

ii. Each MRMIAP has four interfaces. Three of them are the same as those in the MRMIs, while the last one is a WLAN interface that communicates with STA nodes on channel 1.

iii. Mobile mesh nodes communicate on channel 0 with MRMIs/MRMIAPs in the hybrid WMN.

iv. MRMIs/MRMIAPs can communicate with each other using channels 0, 2, and 3 on the backbone based on the mentioned algorithm in Figure 3.

```
Suppose that each MRMI has N interfaces (in our study N = 1, 2, 3) with a default
interface i = 0
Input:
        X : A packet which is arrived on interface j
Output:
        Interface i for sending packet X
To generate list S which is the set of interfaces through which it is possible to send
packet X as the next hop
If packet X is received from a neighbor on interface j   {
        S = S - {j}                 //otherwise the packet is received from upper layers
}
If S is Empty {
        Send packet X through interface i = 0                    // default interface
}
Else {
  If Interface i ε S is in IDLE state {
        Send packet X through interface i
  }
  Else {   // there is no IDLE interface
        Find interface i ε S such that Queue.Lenght(i) is the smallest one
        Send packet X through interface i
  }
}
```

Figure 3. The operation of a MRMI/MRMIAP.

Actually, a MRMIAP can forward a received packet whose destination is an STA node through WLAN interface on channel 1. However, using an MRMI/MRMIAP, the packet will be sent through channel 0 if the destination is a mesh node. Using this solution, an MRMI/MRMIAP extracts a list with the possible output interfaces and selects the output interface as depicted in the algorithm when it needs to send a packet to another MRMI/MRMIAP.

Based on this algorithm, the node firstly generates a list S, which is the set of interfaces from which it is possible to send packet X as the next hop. Then it excludes the interface j from which the packet was received. This avoids interframe interferences. The packet will be sent through the default interface $i = 0$ if no interface remains in the set S. Otherwise, the node searches for an IDLE state among the potential communication interfaces. Using an IDLE state instead of a busy channel reduces the end-to-end delay and avoids more collision. These two reductions are very important in live video streaming over WMNs.

If there are many IDLE interfaces towards the destination, the node will select the interface with the highest number. Conversely, the node selects the interface with the fewest number of packets in its output queue if no interface is in the IDLE state. It is necessary to point out that the node selects the interface that has not been used for a longer time if several interfaces have the same queue size. This avoids the use of common channels that are shared with the nonmultiinterface nodes. Moreover, the received packet on an interface can be discarded if there is no interface for sending the packet out. As can be observed, the presented algorithm is simple to be implemented. It is necessary to note that the costs of equipping MRs with multiple interfaces are insignificant in comparison with MRs with just one interface.

The static nature of MRs can be exploited by applying efficient multiinterface routing protocols. The assignation of the interfaces to use can benefit from the static positions.

5. Simulation

5.1. Simulation parameters

The advantages of using the MIMC capability and the proposed channel selection are assessed by a study based on simulations. In particular, this section evaluates the performance of the GREENIE and the most recently used routing protocols in a hybrid WMN. We have used the INETMANET framework in the OMNET++ (www.OMNETPP.org) simulator. The evaluated routing protocols are GREENIE, OLSR (a proactive routing protocol), AODV (a reactive routing protocol), and the spanning tree (a proactive approach). For the implementation of AODV, we have configured the DYMO code. Specifically, the path accumulation feature is disabled. Alternatively, for the spanning tree (SPT), DYMO has been modified so that the root sends a periodic RREQ message. Intermediate nodes broadcast the RREQ and answer it with a RREP message at the same time [23]. In this way, a bidirectional tree structure is constructed. We have based the coding of AODV and SPT on DYMO because its implementation and design are easier.

DYMO follows the following steps to discover a route towards the destination. Firstly, an RREQ message, which includes an ordered list of the existing nodes towards the destination that it has already visited, will be broadcast on the WMN for discovering a new path by each node. Every node that receives the RREQ message will record a route back towards the source. In the second step, as soon as the final destination receives the RREQ message, it immediately sends an RREP message back to the source of the RREQ message. This message follows the path that the RREQ message traversed, but in the reverse direction. Therefore, all intermediate nodes can record the final path from the source to the destination for passing user data. Finally, a 2-way route is successfully established between the source and the destination when the source of the RREQ message receives the RREP.

It is necessary to highlight that we do not consider HWMP in our evaluation, because, according to our previous study [6], the performance of this protocol is not comparable with others in a dynamic WMN. This evaluation is performed under two scenarios. In the first scenario, MRs are equipped with MIMC capability, whereas no MR is equipped with this capability in the second scenario. The video source disseminates 2000 s of the Silence of the Lambs, a single-layer live video stream based on the G16B1 structure ($IB_1P_1B_2P_2B_3P_3B_4P_4B_5P_5B_6P_6B_7P_7B_8$) with mean frame bit rate = 216,755 bit/s, quantizer parameter (QP) = 8 and frame per second (FPS) = 30, available from (http://trace.eas.asu.edu/mpeg4/index.html) to all the STA nodes. Actually, no mesh nodes request video stream.

Each node can join or leave the network randomly. Moreover, the node distribution is based on a random distribution model. The video source can encapsulate more than one video frame in a packet. This refers to the aggregation mode. The Table shows the considered network conditions, parameters, and their values in the performed simulation. In contrast to the STA nodes, mobile mesh nodes can move with high speed and can be embedded in a vehicle such as a bicycle, a car, or a motorbike. An STA node can stop for a specific time, which can be selected between 80 to 600 s randomly. Finally, the simulation ran 20 times for each protocol with different seeds.

Table. Simulation parameters.

Parameter	Value(s)	Parameter	Value(s)
Simulation time	2000 s	Number of STA	10,30,70,130,200
Distribution model	Uniform(15,36) mps	Number of mesh	14
Mesh mobility speed	Uniform[525] mps	STA mobility speed	Uniform[1..2] mps
Pause time in STA	Uniform[80,600] s	MTU	1500 B
Transmission range of MRs, STA/mesh	160/150 m	Propagation model	Two ray
Interference model	Additive	Hello interval in OLSR	2 s
Network area size	800 × 1200 m^2	Video stream type	VBR
Live video source	Silence of the lambs	Route life time (in DYMO)	10 s with link layer feedback
Routing protocols	GREENIE, proactive (OLSR), reactive (DYMO/reactive (AODV)), spanning tree (DYMO)		

6. Performance metrics

We focus on several performance metrics to provide a comprehensive evaluation of the proposed MIMC algorithm. These metrics are as follows:

i. The total capacity of successfully received video packets ($TSRP$): this metric indicates the capacity of the successfully delivered video packets in bytes generated by each routing protocol and with the destination being a STA node.

ii. End-to-end delay (EED): it indicates the time required for transferring a video packet from the source to a destination node. It is measured in milliseconds (ms).

iii. Packet delay variation (PDV): Jitter is another name for it. It is also measured in milliseconds.

iv. Video distortion: This performance metric refers to the ratio of the not playback to the total capacity of all the video frames. This metric is measured in percent.

v. Video frames: This performance metric refers to the number of received video frames I, P, and B.

6.1. Simulation results and discussion

Figures 4 to 8 show the averaged values for video distortion, TSRP, EED, PDV, and the number of received video frames when there is a different number of STA nodes. According to Figure 4, GREENIE, OLSR, AODV, and the spanning tree routing protocols improve the video quality about 52.86%, 2.94%, 27.58%, and 26.37% using MRMIs/MRMIAPs. This clearly shows that all routing protocols provide better video quality when MRs are equipped with a multiinterface feature. However, GREENIE efficiently exploits the advantages of MRMIs/MRMIAPs in comparison with others because it effectively uses the backbone of a WMN for routing packets. In this figure, the proactive protocol provides approximately the same video quality with and without the multiinterface feature. The fact is that STA nodes have low mobility speed. Therefore, proactive can efficiently route packets among them without using the backbone significantly.

Figure 5 confirms the results obtained in Figure 4. In fact, all routing protocols, especially GREENIE, provide a higher amount of TSRP on STA nodes using MRMIAPs. As can be seen in this figure, GREENIE delivers the largest amount of frames in bytes even if MRs are not equipped with the multiinterface feature. In this regard, GREENIE provides about a 52% and 44% higher amounts of TSRPs in STA nodes with and without the multiinterface feature in comparison with other routing protocols when they use MRMIs/MRMIAPs, respectively.

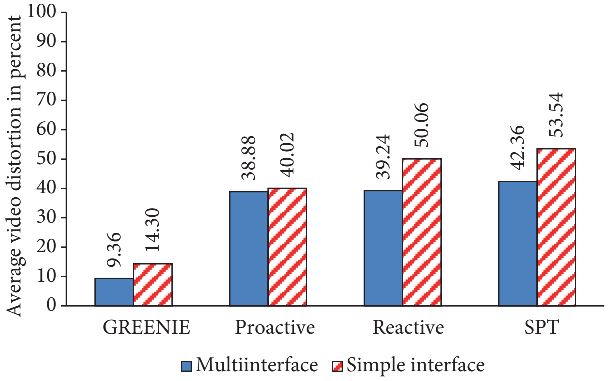


Figure 4. Average video distortion in percent in STA nodes.

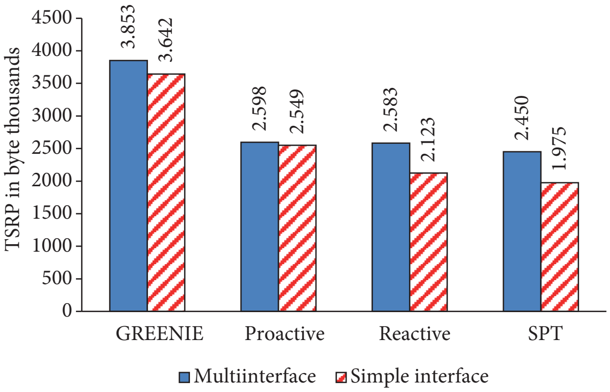


Figure 5. Experienced TSRP in bytes in STA nodes.

Figure 6 indicates that the end-to-end delay is also considerably decreased. GREENIE shows that it introduces the lowest EED with and without the multiinterface capability on MRs. Altogether, all routing protocols delivered video frames in less than 2 ms using MRMIs, which is a suitable time in live video streaming. This is similar for PDV as depicted in Figure 7.

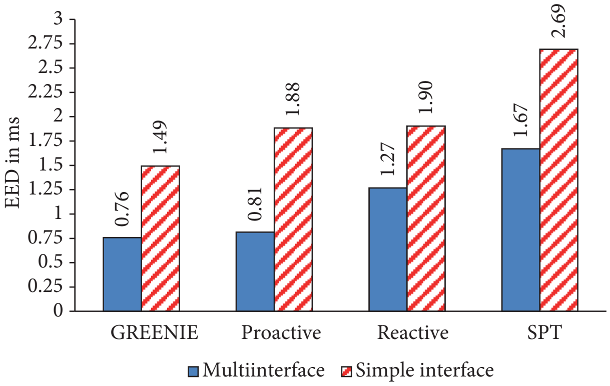


Figure 6. Experienced EED in ms by STA nodes.

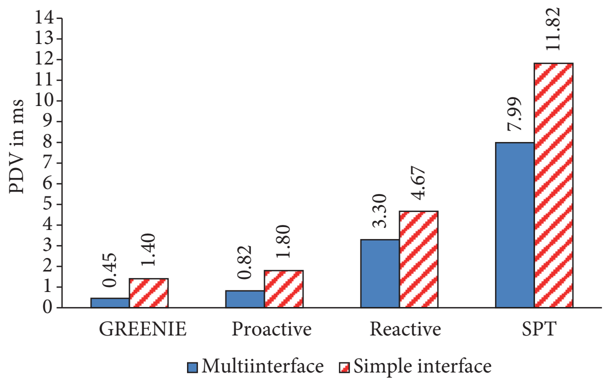
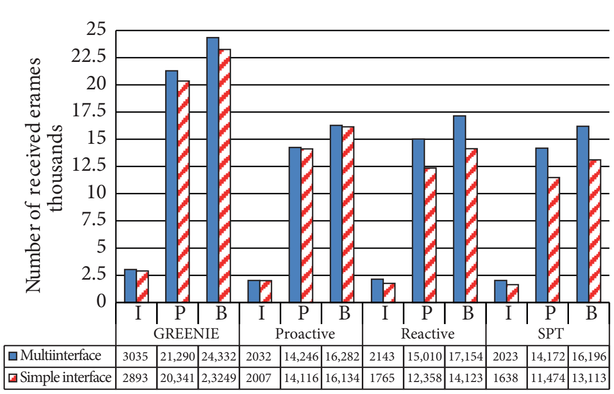


Figure 7. Experienced PDV in ms by STA nodes.

OLSR and SPT routing protocols can provide a significant performance in a WMN when there are some nodes with low mobility speed such as STA nodes. However, what can be inferred from Figures 4 to 7 is that GREENIE does not only considerably outperform proactive, but it also works better than other routing protocols in terms of the video distortion, TSRP, EED, and PDV. Therefore, it provides better video quality on STA nodes, especially when MRMIs/MRMIAPs exist in the WMN.

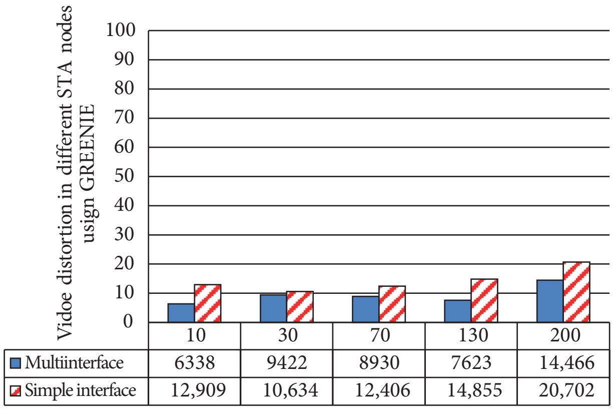
The number of received video frames is another important metric for measuring the performance of a routing protocol in live video streaming. Recall that there are dependencies among video frames in a GoP. For example, no video P and B frames can be successfully decoded if the I-frame is not received or decoded yet. Figure 8 shows the average number of received video frames in STA nodes using the considered routing protocols. According to this figure, GREENIE provides the highest number of video frames in STA nodes with and without the multiinterface feature. As a result, it can provide better video quality on nodes.

Video distortion is the most important metric for measuring the performance provided by a routing protocol in live video streaming. Figures 9 to 12 depict the video distortion experienced by a different number of STA nodes when GREENIE, OLSR, AODV, and the spanning tree routing protocols are employed.



	GREENIE			Proactive			Reactive			SPT		
	I	P	B	I	P	B	I	P	B	I	P	B
■ Multiinterface	3035	21,290	24,332	2032	14,246	16,282	2143	15,010	17,154	2023	14,172	16,196
▨ Simple interface	2893	20,341	2,3249	2007	14,116	16,134	1765	12,358	14,123	1638	11,474	13,113

Figure 8. Number of received video frames in STA nodes.



	10	30	70	130	200
■ Multiinterface	6338	9422	8930	7623	14,466
▨ Simple interface	12,909	10,634	12,406	14,855	20,702

Figure 9. Experienced video distortion in percent in STA nodes (using GREENIE).

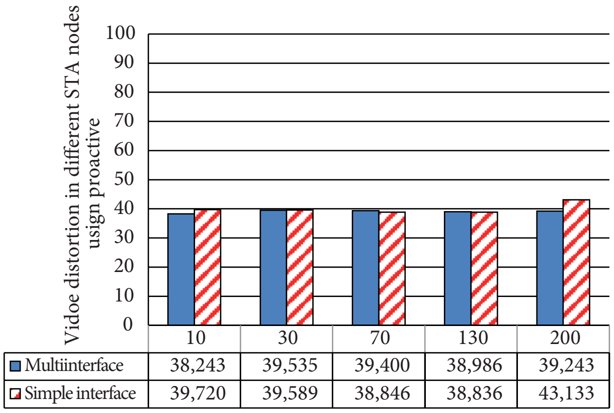
Similarly to the proactive routing protocol, GREENIE introduces approximately the same video distortion when the number of STA nodes varies. However, these nodes experienced a reduced video distortion using GREENIE. Moreover, contrary to proactive, GREENIE efficiently exploits the advantages of MRMIs/MRMIAPs for a different number of STA nodes by introducing a lower level of video distortion. Figures 11 and 12 depict that the performance of AODV and the spanning tree routing protocols considerably decreases when the number of STA nodes is greater than 70.

To have a more comprehensive evaluation and according to the importance of video distortion, we also measured the value of this metric when aggregation is not used. In this regard, only one video frame can be encapsulated in a packet. Figure 13 shows the obtained results. Similar to the aggregation mode, GREENIE efficiently exploits the advantages of the proposed MIMC algorithm by introducing less amount of video distortion to the network.

As a final result, results show that the proposed MIMC algorithm increases the performance of all the routing protocols, especially GREENIE, by decreasing the video distortion, end-to-end delay, PDV, and interferences on nodes. These reductions result in a higher network throughput and smooth video playback on nodes. In fact, TSRP is improved by all routing protocols when they employ our MIMC algorithm. As a result, the proposed algorithm increases the network throughput.

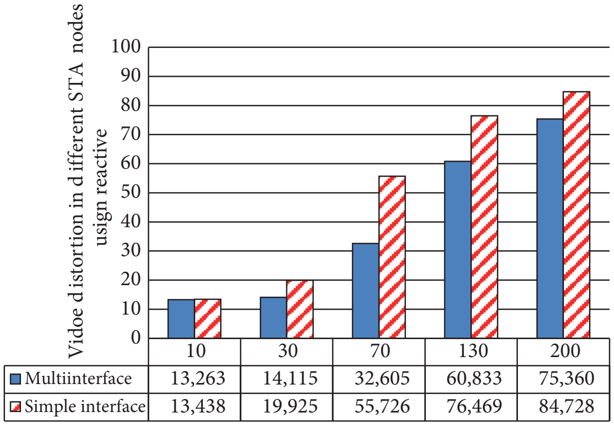
7. Conclusion

Video streaming over hybrid wireless mesh networks introduces many challenges, because interferences, contentions, and collisions can be increased when the number of nodes increases. In a hybrid WMN, there are



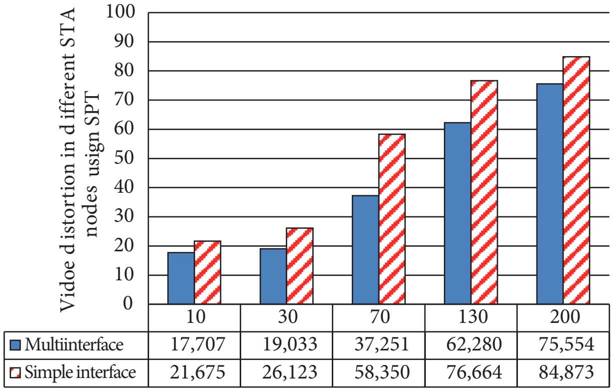
	10	30	70	130	200
■ Multiinterface	38,243	39,535	39,400	38,986	39,243
▨ Simple interface	39,720	39,589	38,846	38,836	43,133

Figure 10. Experienced video distortion in percent in STA nodes (using proactive).



	10	30	70	130	200
■ Multiinterface	13,263	14,115	32,605	60,833	75,360
▨ Simple interface	13,438	19,925	55,726	76,469	84,728

Figure 11. Experienced video distortion in percent in STA nodes (using reactive).



	10	30	70	130	200
■ Multiinterface	17,707	19,033	37,251	62,280	75,554
☐ Simple interface	21,675	26,123	58,350	76,664	84,873

Figure 12. Experienced video distortion in percent in STA nodes (using SPT).

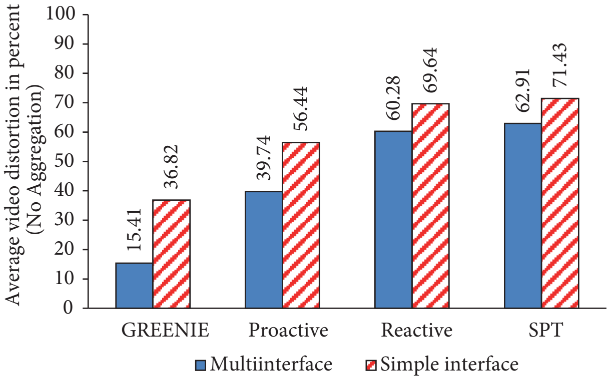


Figure 13. Average video distortion in percent in STA nodes (no aggregation).

some STA nodes that work in infrastructure mode and have low mobility speed. Actually, most of the nodes in a real WMN are STA nodes. In order to provide high video quality on these nodes, it is necessary to have an efficient routing protocol. Although GREENIE fulfills this requirement by introducing low video distortion on the nodes, its performance slightly decreases when the number of nodes, especially STA nodes, increases. To overcome this limitation, this study introduces an efficient multiinterface, multichannel algorithm on mesh routers (named MRMI). Using MRMIs/MRMIAPs, all routing protocols provide better video quality on STA nodes. However, GREENIE exploits the advantages of MRMIs more than others, because it efficiently uses the backbone of a WMN. The simulation results demonstrate that it increases the network scalability while the video quality remains almost high.

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