

Strategic Network Model for Real-Time Video Streaming and Interactive Applications in IoT-MANET



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Abstract In this paper, we discuss how to handle the issue of energy loss, delay during processing and transmission in IoT-MANET for real-time applications such as video in surveillance networks and also interactive applications in smarthome. Here, we propose a hierarchical strategic network model to reduce the cost of computation, latency and energy consumption. The proposed model when compared with random and normal grid topology gives better performance. Results of comparison show that the proposed hierarchical model provides an average of 166.29 Mbps for bandwidth utilization, 63.92 Mbps of throughput, 0.000095 s of jitter and 12.28 % of packet loss for transferring video data in mobile conditions. Also, each supernode receives an average 6.22 frames per second out of 15 transmitted frames.

Keywords Intelligent collaboration · Video streaming · Edge-MANET

1 Introduction

In contemporary researches, mobile edge computing components are integrated with MANET, WSN [6] and IoT to build up smartspaces [1]. IoT-MANET [1] has been built as a small but scalable network to support a variety of applications such as smart-building/homes, precision farming, defence surveillance, augmented reality. For our daily well-being, these technologies support things of various types to interact among themselves. For example, depending on the ambient temperature, the automatic air-conditioning in a smarthome system may adjust its cooling effect. These interactions may not involve exchange of a large amount of data or consuming enough network bandwidth, however, in some cases challenge is low latency and real-time decision

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making at the edge which involves the use of efficient network design and intelligent collaboration among nodes. Associated edge technologies include fog, cloudlets, edge-based MANET technologies [3]. Also, in these contexts, some processing is best done at the edge due to security reasons. Here, mobile edge computing [4] uses high computing resources at strategic locations to facilitate processing and storage in real time. It aids real-time application by enabling data fusion and intelligent decision making from multiple sensor devices. For example, in a tactile network, processing video surveillance data for target tracking in real-time requires high network bandwidth, low latency and low jitter which are best supported in edge rather than the cloud. Hence, in both surveillance and interactive cases discussed above, the challenge is to design a network that can reduce communication delay (which affects response time) and energy consumption (which directly affects network lifetime). Therefore, the purpose of this research work is to find a network design to reduce the energy consumption (due to complex computation and data transmission) and delay for resource-constrained IoT/edge-based MANET nodes which support different types of applications. Therefore, in this paper, we propose a hierarchical strategic network model and compare the same with random and grid topology. We also check the performance of a video streaming application and an interactive application in these three topologies over various layer-2 and layer-3 routing protocols of MANET. The results of the comparison are obtained in NS3 simulator with selected parameters such as average throughput, bandwidth consumption, packet delay, jitter, packet loss and also video frames per second (FPS) received at the sink.

The paper is organized as follows. Section 2 describes the hierarchical model of the network, Sect. 3 discusses the strategic approach, and Sect. 4 discusses the simulation parameters. Results are discussed in Sect. 5. Paper is concluded in Sect. 6.

2 Hierarchical Model

We consider a heterogeneous network cluster as shown in Fig. 1. Here, twelve ordinary nodes (red), R_{ij} , distributed throughout the network, with limited resources are used primarily for data collection and routing. These are equipped with cameras and stream video feeds to more powerful super nodes. These ordinary nodes may or may not have GPS, from which they ascertain their location. They communicate with other R_{ij} and also with supernodes to transmit video, image, audio, text data and also control information.

The other nodes, in the above scenario, responsible for intelligent processing are called supernodes (SuN) or cluster head (CH) used interchangeably in this paper. In Fig. 1, there are four supernodes (green) equipped with GPS (e.g. laptops). They have higher energy, storage, computation capability and high antenna gain to cover areas larger than R_{ij} 's. Each of them is equipped with a camera. Hence, they can also detect objects under the coverage area they are monitoring. They communicate with the ordinary nodes, collect data, aggregate and process them and send a collective decision to base station (BS). For example, CH can process the image frames of

transmitted video from R_{ij} s and decide the number and type of target. It can also find target's possible location and future direction collaborating with other CHs. If no such information is revealed, the supernode may refrain from sending to BS. Moreover, these CH's have no/lower mobility compared to R_{ij} s. The purpose of dividing the area in Fig. 1 is to reduce the number of hops and mitigate interference by restricting the number of control information within a MANET. We call this a hierarchical model for data collection and efficient processing.

3 Strategic Approach

In this approach, we divide the large network coverage area into small grids to reduce the number of hops and induce quicker communication between source to destination. The entire $1000\text{m} \times 1000\text{m}$ area is subdivided into zones to place sixteen nodes as shown in Fig. 1. In a typical zone ($A1, B2, C3$ and $D4$), we place three mobile R_{ij} that can communicate with CH. We denote CH_A, CH_B, CH_C and CH_D as cluster heads in each zone. For example, R_{11}, R_{12}, R_{13} in zone $A1$ communicate with CH_A within four hops. However, if we used 12 randomly placed nodes, the number of hops and control message exchange could have been higher in case there is route reconfiguration due to mobility of nodes. Therefore, this placement strategy also reduces the number of control messages in the MANET. Here, each R_{ij} moves inside the $(250\text{m} \times 250\text{m})$ region and does not move to other zones. Each CH collects zone information from R_{ij} and communicates among themselves and routes to BS also within four hops. Blue lines in Fig. 1 represent hop count. Hence, with this approach, the number of hops can be reduced from source to sink with less

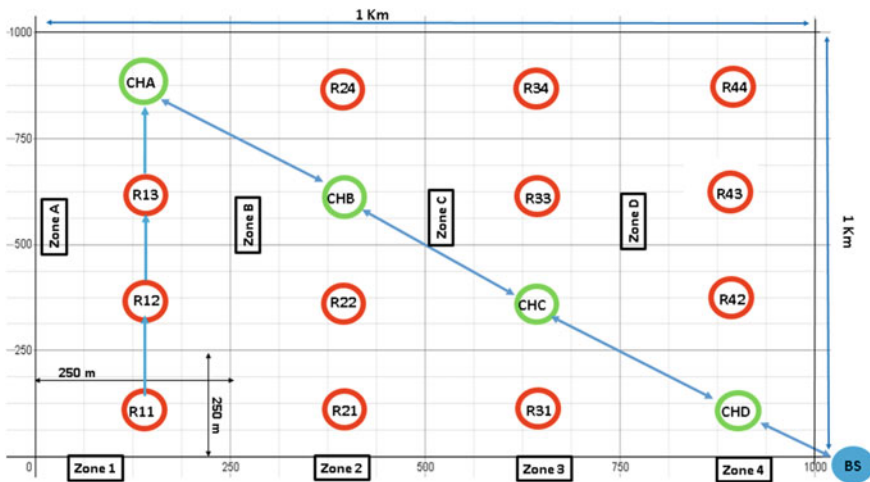


Fig. 1 Strategic placement of nodes

Table 1 Simulation parameters-1

Parameter	Value
<i>General</i>	
Simulation time	300
Total number of nodes	16
Number of source	12
Number of sinks	4
Coverage area	1000 × 1000 m ²
Data rate	331,776 kbps(15 FPS)
Packet size	1472 Bytes
<i>Physical layer</i>	
Transmission power	30 dBm
Tx antenna gain	9 dBi
Rx antenna gain	9 dBi
Propagation loss model	FriisPropagationLossModel
PropagationDelayModel	ConstantSpeedPropagationDelayModel
<i>MAC layer</i>	
WiFi standard	WIFI_PHY_STANDARD_80211ac
RemoteStationManager	ns3::ConstantRateWifiManager
DataMode	VhtMcs8
ControlMode	VhtMcs8
MCS	8
ChannelWidth	80
Nodes 0–3 channel number	106 (80 Mhz) 5 Ghz frequency
Nodes 4–7 channel number	122 (80 Mhz) 5 Ghz frequency
Nodes 8–11 channel number	138 (80 Mhz) 5 Ghz frequency
Nodes 12–15 channel number	155 (80 Mhz) 5 Ghz frequency

than five hops reducing latency and data loss during transmission. We also used different frequencies or channel numbers, shown in Table 1, to mitigate inter-cluster interference among nodes during data transmission from R_{ij} to SuN.

4 Simulation

To check how our proposed grid performs compared to random and generic grid topology, we simulated the above scenario in NS3. Here, we perform three test simulations as scenarios-1 (random), 2 (grid) and 3 (proposed grid -p_grid). We have used scenario-1 for random topology as shown in Fig. 2a where all 16 nodes are randomly placed inside 1000 m × 1000 m area. Here, any source node can send

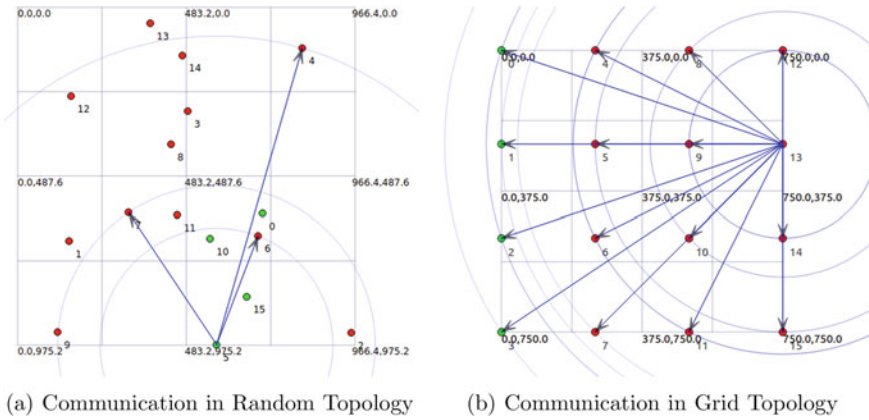


Fig. 2 Communication at different instants in random and grid topologies

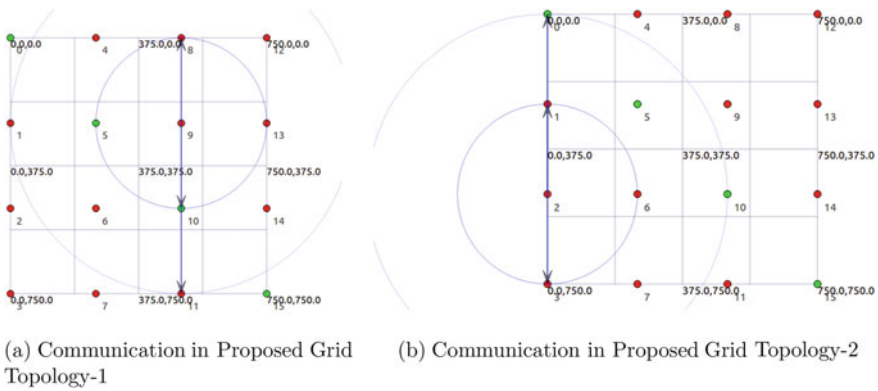


Fig. 3 Communication at different instants in proposed grid topology

data to any other sink node. In scenario-2, we placed the nodes in a grid $[4 \times 4]$ as shown in Fig. 2b. The distance between each node is 250m. Here, any node can send collected data to other sink nodes. Green nodes represent sink placed in the first column of the grid. Scenario-3 shows the proposed grid in Fig. 3a, where each node is restricted to move around a bounded rectangle of $250\text{m} \times 250\text{m}$. Nodes under the supervision of a particular SuN cannot move to other zones. When any node hits the boundary, it bounces back and chooses another direction. Simulation parameters are detailed in Tables 1 and 2.

Table 2 Simulation parameters-2

Parameter	Value
Mobility model	ns3::RandomWaypointMobilityModel ns3::ConstantPositionMobilityModel
Node speed	1.94 m/s
Node pause time	2 s
Topology (grid)	GridPositionAllocator
MinX, MinY	0.0, 0.0
DeltaX, DeltaY (Distance Between Nodes)	250.0, 250.0
GridWidth	4 nodes per column wise
Topology (Random)	RandomRectanglePositionAllocator
16 nodes placed randomly inside $1000 \times 1000 \text{ m}^2$	
X length	1000 m
Y length	1000 m
Topology (Proposed grid)	RandomRectanglePositionAllocator
Single node is randomly placed inside a restricted area of $250 \times 250 \text{ m}^2$ (For each 16 nodes, each rectangle is chosen so that they do not move to other zone)	
X length	250 m
Y length	250 m
Routing protocol	Global, AODV, OLSR, DSDV, HWMP
Packet interval	0.1 s
IP address	10.1.1.0/24
Transport layer	UDP
Application layer	
I-server and I-client	Sends and receives simple text-message
OnOff application	Video streaming
OffTime	ns3::LogNormalRandomVariable [Mu=0.4026 Sigma=0.0352]
OnTime	ns3::WeibullRandomVariable [Shape=10.2063 Scale=57480.9]
MaxBytes	10,989,173
Server start and stop time	0, 300 s
Client start and stop time	0.1 s after server, 299 s

Table 3 Bandwidth comparison for three scenarios

	Bandwidth (Random)	BandWidth (Grid)	Bandwidth (P_Grid)
Video (Static) (Mbps)	196.34	209.22	217.59
Video (Mobile) (Mbps)	150.86	160.65	166.29
Interactive (Static) (Kbps)	159.67	160.34	162.36
Interactive (Mobile) (Kbps)	158.71	158.12	160.36

Table 4 Comparing packet delay for three scenarios

	Delay (Random) (s)	Delay (Grid) (s)	Delay (P_Grid) (s)
Video (Static)	16.12	13.52	10.47
Video (Mobile)	21.78	22.25	18.99
Interactive (Static)	0.00230	0.00238	0.00237
Interactive (Mobile)	0.00353	0.00272	0.00261

5 Results and Discussion

A. Comparing Bandwidth Utilization

Tabulated results are average of all layer three (L3-AODV, OLSR, DSDV, etc.) and layer two (L2-Hybrid Wireless Mesh Protocol (HWMP)) routing protocols used in this paper. Table 3 provides overall results of the comparison of bandwidth in three scenarios for L3 and L2 protocols. Theoretically, we know a higher bandwidth network allows transferring more data. Also, we can observe in the case of video and interactive applications that random topology has the lowest, but proposed grid has the highest bandwidth utilization on average for all MANET protocols used above. These results show that bandwidth utilization of networks can vary by changing network topology, type of MANET routing protocol and mobility of nodes.

B. Comparing End-to-End Delay

Term delay is used in this paper to refer to packet delay or average end-to-end delay as per [2]. Table 4 shows packet delay for three topologies in static and mobile condition. In Table 4, packet delay in the proposed grid for both video and interactive applications shows minimum delay compared to other topologies.

Table 5 Comparing jitter for three scenarios

	Jitter (Random) (s)	Jitter (Grid) (s)	Jitter (P_Grid) (s)
Video (Static)	0.0001029	0.0000882	0.0000705
Video (Mobile)	0.0001108	0.0001137	0.0000946
Interactive (Static)	0.002133	0.001324	0.001481
Interactive (Mobile)	0.002034	0.001634	0.001435

Table 6 Comparing throughput for three scenarios

	Throughput (Random)	Throughput (Grid)	Throughput (P_Grid)
Video (Static) (Mbps)	74.57	83.78	104.45
Video (Mobile) (Mbps)	60.33	53.29	63.92
Interactive (Static) (Kbps)	81.24	80.72	81.27
Interactive (Mobile) (Kbps)	80.37	79.92	80.85

C. Comparing Jitter

Packets with high jitter can pause the video for few moments, and in the worst case, it may also induce packet loss at the receiver. We calculated mean jitter from paper [2]. In Table 5, mean jitter values of all three topologies are tabulated for video and interactive application where video application in proposed grid shows significantly lower jitter than interactive application.

D. Comparing Throughput

As bandwidth provides an estimate of how much data can travel, while throughput provides actual value of transmitted data. We calculated throughput using formula from paper [5]. Table 6 shows throughput decreases due to mobility in both video and interactive applications. Proposed grid shows a higher throughput in both video and interactive applications.

E. Comparing Packet Loss

Percentage of packet loss is calculated with respect to number of packets sent. Table 7 shows packet loss comparison for three topologies in static and mobile conditions for video and interactive data. We can observe that mobility-induced packet loss is slightly higher in all three topologies. Also, interactive application shows a lower

Table 7 Comparing packet loss for three scenarios

	PacketLoss (Random) (%)	PacketLoss (Grid) (%)	PacketLoss(P_Grid) (%)
Video (Static)	11.39	11.06	7.08
Video (Mobile)	13.92	13.60	12.28
Interactive (Static)	1.74	3.12	0.41
Interactive (Mobile)	4.86	5.87	2.75

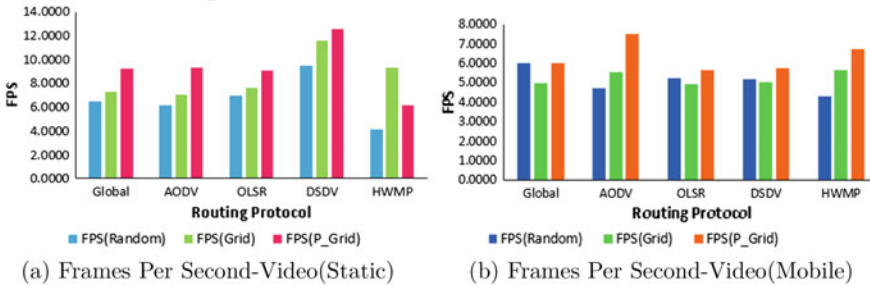


Fig. 4 Comparing frames per second for video application

Table 8 Comparing FPS for three scenarios

	FPS (Random)	FPS (Grid)	FPS (P_Grid)
Video (Static)	7.28	8.37	10.03
Video (Mobile)	5.28	5.12	6.22

packet loss percentage compared to multimedia data transfer as expected. The proposed grid has a minimum packet loss percentage among three scenarios.

F. Comparing Frames Per Second

We measure the number of frames received at the sink for three topologies for video data transfer at 15 FPS from each source. Figures 4a, b show FPS in static and mobile conditions, respectively. HWMP protocol has 5.5 FPS on average in three topologies in mobile condition. For others, FPS drops in the range of 4.3–7.5 for all three scenarios during mobility. Comparison of FPS is shown in Table 8, which also depicts that the proposed grid has the highest FPS for video application tested here.

6 Conclusion

In this research work, we propose a hierarchical strategic network model to reduce the cost of computation, latency and energy consumption for IoT/edge- based MANET technology for real-time multimedia (surveillance in tactile networks) and interactive (smarthome) applications. We designed a cluster-based distributed network with IoT-MANET over 802.11 ac to mitigate the problem of computation and delay. This network topology considers the reduction of number of hops and number of messages aggregated at the cluster head by restricting the number of nodes inside the zone. Also to mitigate inter-cluster interference, each zone has been assigned a different channel. Results show that proposed hierarchical strategic network model performs better in transmitting both multimedia (streaming video) and text-based interactive applications for IoT-MANET and, hence, can be deployed in surveillance and smarthome applications.

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