Evaluation of Topology Effects on the Performance of Motorway Surveillance System

L. A. Hassnawi[1], R.B Ahmad, Abid Yahya, S. A. Aljunid
School of Computer and Communication Engineering, University Malaysia Perlis, Malaysia
02000, Kuala Perlis - MALAYSIA
[1]laythmail@yahoo.com

Abstract--Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Applications for the use of wireless networking have become increasingly popular and more sophisticated. One of the most important applications based on the use of wireless networks is for motorway surveillance. In a wireless Motorway Surveillance System (MSS), a series of cameras capable of transmitting images wirelessly are placed along a roadway. In an 'infrastructure-less' MSS, one important consideration is the placement of the cameras in a specific topology. Topology imposes several constraints on the amount of data of images that can be transmitted through the network, which leads to effects on the network's overall performance. This paper evaluates and analyzes the effects of topology on the performance of a motorway surveillance system comprised of wireless cameras placed along a roadway. Two different types of configurations were considered: single line topology and double line topology. These topology configurations can be used as a starting point for the initial design of a new MSS based on an 'infrastructure-less' network. The main purpose of the new design would be to enable the motorway users to quickly access data (images) collected by wireless cameras placed along a motorway in order to stay informed of driving conditions. It is a conclusion of this study that the double line based topology results in better network performance as compared to the single line based topology.

Keywords--Cameras Network, Packet loss, Surveillance system, Topology, Throughput.

I. INTRODUCTION

Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Applications for the use of wireless networks have become increasingly popular and more sophisticated. Motorway surveillance is one of the most important of these applications. Based on the use of wireless networking, various designs have been proposed for Motorway Surveillance Systems (MSS) using different configurations of wireless cameras. Transporting surveillance data collected by cameras over wireless networks has benefits including reduction of costs and increased flexibility over wired systems.

In the traditional wireless Motorway Surveillance System (MSS), which uses infrastructure wireless networking, the system is designed to send information to a predetermined location, known as the "Base Station" for processing and monitoring, or else to Gateway Points that then send all the information to the Base Station [1]. One design flaw that needs improvement is that the traditional system does not provide fully effective access to the MSS network for the users of the motorway. For example, not all vehicles have access to the Base station or to the Gateway Points in situations in which the distance from the vehicle to any gateway is too far, thus the need to add more base stations.

Our previous work [2] proposed and evaluated the design for a new type of 'infrastructure-less' MSS. The proposed system utilizes a new image acquisition technique that enables the motorway users (the drivers of vehicles) to access this system by requesting images from any camera within the network while driving the vehicle. The motorway user can view the road and traffic conditions without the necessity for any additional infrastructure or centralized administration.

The proposed system is comprised of a number of IP cameras. These cameras are distributed along the motorway and connected with each other to form a new type of network, which we have named the "Wireless Ad-Hoc Camera Network (WAHCN)". The operation of this network is based on the operation of the existing mobile ad-hoc networks (MANETs); therefore, it inherits all the features of the MANETs.

To understand and model networks, the connectivity and the network capacity are two fundamental aspects to consider. A further consideration is the specific topology of the network. The topology imposes several constraints on the amount of data that can be transferred through network, which leads to effects on its performance. The underlying distribution of the camera nodes can have not only quantitative but also qualitative effects on the network. The location of the cameras within a specific topology is one of the most important parameters of a design for a wireless MSS. Topology may affect the loss of packets, and consequently, the overall network performance.

The objective of this research was to investigate different topologies for camera node placements in a wireless network and to analyze the effects of changes to topology on the performance of a motorway surveillance system.

The contribution of this paper is to offer an evaluation of the effects of two different network topologies on the performance of a model wireless motorway surveillance system (MSS) in order to find the best deployment of the camera nodes.

The remainder of this paper is organized as follows: Section 2 presents the related work of other authors. Section 3 describes two topologies that can be used for an MSS. Section 4 presents the model setups, and performance metrics. Section 5 presents the results and discussion. Finally, Section 6 concludes the paper.

II. Related Work

A number of studies have been undertaken to analyze and evaluate the effects of network topology and camera location on the performance of surveillance systems. Mantzel et al [3] proposed a new distributed localization algorithm for networks of cameras with a sparse overlapping view structure that is energy efficient and copes well with networking dynamics. The authors showed that the distributed nature of the localization computations could result in order-of-magnitude savings in communication energy over centralized approaches.

Petrova et al [4] studied the effects of different node distributions on the local throughput of the slotted ALOHA MAC protocol. The simulation results of this study showed that non-uniform random node distributions have a strong impact on the local throughput, which are related to the network capacity and performance. In theory, this means that the node topology should be taken into account in more detailed analyses and simulations of ad hoc, sensor, and mesh networks.

Shie et al [5] showed that the mismatch between the logical network topology constructed by a peer-to-peer (P2P) application and its underlying physical network topology can have significant impacts on the performance of the P2P application. In this study, the authors evaluated effects on the downloading performance of the BitTorrent (BT) protocol using the NCTUns network simulator and a real-life BitTorrent application. The results of the simulation showed that the underlying physical network topology significantly affects the performance of P2P applications.

Lobaton et al [6] described a surveillance system using many cameras that cover a wide and complex area and the topologies that can be used to get optimal system performance. Detmold et al [7] demonstrated that surveillance camera technologies have reached the point whereby networks of a thousand cameras are not uncommon. These authors focused on determining the active topologies of the camera networks for wide area surveillance systems.

III. Topology Analysis

The topology of a MSS is a very important parameter as it may affect the packet loss rate, and consequently, the overall network performance. Camera nodes for a MSS are distributed along a model motorway in a line topology, because given the typical design of ‘real world’ motorways, camera nodes can only be placed in a linear configuration on the road. In this paper, two scenarios are suggested for distribution of camera nodes based on line topology. These are:

a. Single line topology.
b. Double line topology.

A. Single Line Topology

In a single line type of topology, all the cameras are distributed along one side of the motorway as shown in Figure 1. The deployment of the camera nodes based on single line topology can be expected to reduce the level of the performance of the MSS. This is because the distribution of the cameras in a single line means that there is only a single path for transporting the data between sources and destinations. When the number of users increases, the channel contention and hidden terminal problems occur along this unique path are increase, which leads to an increase in packet loss and more transmission delay. Consequently, when cameras are placed in a single line topology, the performance level of the MSS can logically be expected to decline.

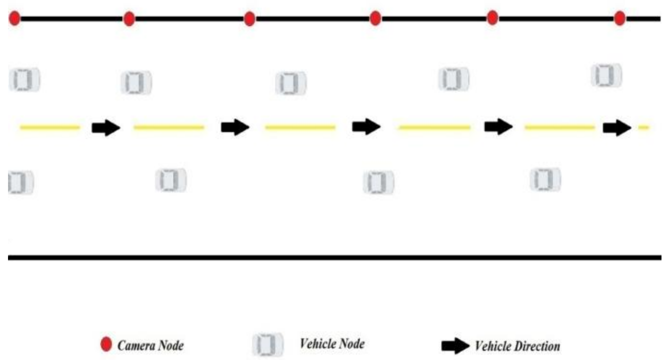

Figure 1. Single line topology

B. Double Line Topology

In a double line type of topology, cameras are distributed on both sides of the motorway as shown in Figure 2. The deployment of the cameras in a double line topology allows the routing agent the possibility of finding multiple paths between the sources and the destinations for transport of data. In contrast to single line topologies, the channel contention when using double line topology will be less due to the existence of multiple paths. A greater number of possible paths leads to decreases in packet loss and transmission delays. Consequently, the overall performance of the MSS network can be expected to be better for a double line topology than when cameras are located in a single line topology.

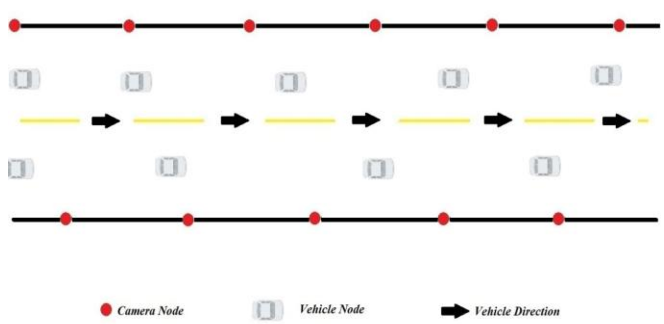

Figure 2. Double line topology

IV. Motorway Model Setup

The cameras network of the MSS scenario is modeled with the following model specifications:

- The simulation scenario is a 6.5 km straight motorway section with two lanes heading in one direction.
- 50 camera nodes are distributed along the motorway in a line topology with 250 meters separation between each two cameras.
- In double line topology, all the cameras of the second line are moved ahead by 125 meters than the cameras of the first line as shown in Figure 2.
- Six vehicles are distributed on the lanes of the motorway and the distance between each two vehicles is 50m.
- The vehicle speeds is selected to be 20 meter/second.
- 512 byte packet size is selected.
- The value of packet rate is selected to be 3 packets / sec.
- All the cameras use UDP traffic sources with a constant bit rate (CBR) pattern.
- OMNET++ default parameters.
- All experiments within each model were tested over 500 seconds simulation time.
- All vehicles move according to the freeway (linear) mobility pattern.

OMNeT++ Ver. 4.1 [8] was used to simulate the motorway models. Simulations with an extensive set of parameters were performed to evaluate and analyze the performance of the MSS under different network topologies. Table 1 shows the parameter setups for the evaluation experiments.

TABLE I. Parameters Setup

Parameter name	**value**
Playground	6250 m * 100 m
Number of Camera Nodes	50
Number of Vehicles Nodes	6
Distance between Camera Nodes	250 m
Packet Size	0.5 KB
Packet Rate	3 Pkt. /s
Vehicle Speed	20 meter/s
Number of Users	1, 2, 3, 4, 5, and 6
Simulation Time	500 s
Routing Protocol	AODV
MAC Protocol	802.11g
Bit Rate	54 Mbps

A. *Performance metrics*

The metrics that were selected to evaluate the proposed MSS network performance are:

- Throughput – represents the average rate of successful packet delivery per unit of time over a communication channel [9].
- Packet Transmission Ratio (PTR) - represents the ratio between the number of packets received by the receiver and the number of packets sent by the source [10].
- Packet Loss- represents the number of lost packets.
- Average packet transmission time (delay) - which is the difference between the time when packet is sent by the camera node and the time when the packet arrived at the vehicle node.

V. Results and Discussion

Topology is a very important parameter that affects the rates of packet loss, which, in turn, has measurable effects on the network performance. Two types of experiments were carried out to evaluate and analyze the impacts of single and double line topology scenarios on the performance of a model MSS. The first experiment evaluated the effects in both topologies with a changing number of users; the second experiment evaluated the effects in both topologies with a changing number of nodes between a source and destination.

A. *Analysis based on Number of Users*

The performance of the MSS was evaluated using different numbers of users in both single line and double line topologies. Figure 3 shows the throughput of the network (in Kbps) versus the number of users. There are two plots, each corresponding to a different network topology. For each topology, the throughput of network traffic decreases with an increase in the number of users. This result seems to be because increasing the number of users will also increase the channel contention and the number of hidden nodes. This situation leads to an increase of the overhead of the MAC layer protocol. Increasing protocol overhead will consume bandwidth, which results in degradations of the network throughput. Furthermore, it can be seen that the throughput when using double line topology is greater by 7.098 % than the throughput when using single line topology. This result is likely because using single line topology means that there is only a single path to transport the data between the sources and destinations for all users. When the path becomes disconnected between a source and destination for any reason, the routing agent is forced to re-discover the same path to connect the sources to destinations again. On the other hand, using double line topology means that the routing agent can find and select from multiple paths to re-establish the connection between the sources and the destinations.

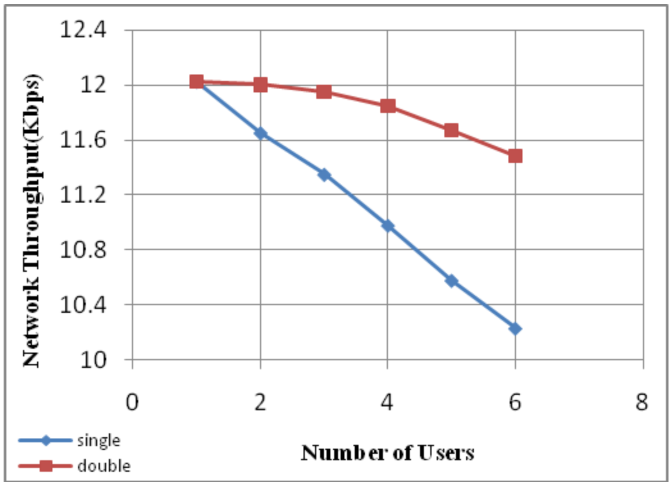

Figure 3. Average network throughput vs. number of users for single and double line topologies

Figure 4 shows that the number of lost packets when using double line topology is less by 35.64 % than when using single line topology. An explanation for this result is because in single line topology, increasing the number of users will increase the channel contention along the single path. Channel contention leads to an increase in the number of lost packets. In contrast, in double line topology, the channel contention is distributed on more than one path, which results in a decrease in the packet loss. The routing agent also has a chance of finding a path with lower channel contention to re-route the connection.

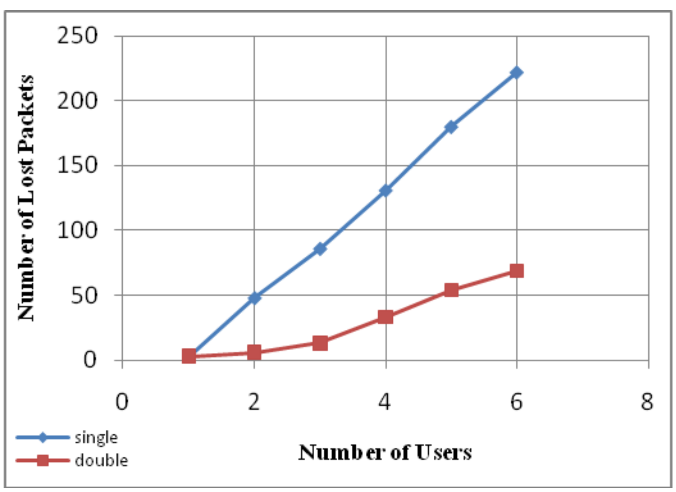

Figure 4. Number of lost packets vs. number of users for single and double line topologies

Figure 5 shows that the Packet Transmission Ratio (PTR) is better in double line topology than in single line topology. The channel contention in double line topology is less as compared to single line topology due to the existence of multiple paths, which allows more data to be sent. This increases the PTR. The number of lost packets in double line topology has been determined to be less than the number of lost packets in single line topology. This result makes the PTR in double line topology better than the PTR in single line topology.

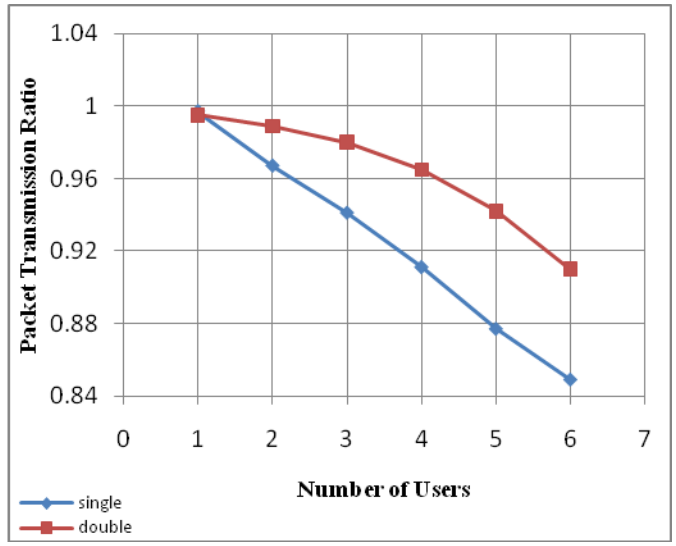

Figure 5. Packet transmission ratio vs. number of users for single and double line topologies

Figure 6 demonstrates the packet transmission time delay versus the number of users for both topologies (single line and double line). The figure shows that the transmission time delay increases with an increased number of users in both scenarios, but the delay time when using single line topology is longer than the delay when using double line topology. Since increasing the number of users will increase the number of packets waiting in the MAC layer buffer to be sent, the nodes also need more time to transmit the data when using single line topology than in double line topology. This is clearly due to the higher channel contention on the unique path of the single line topology.

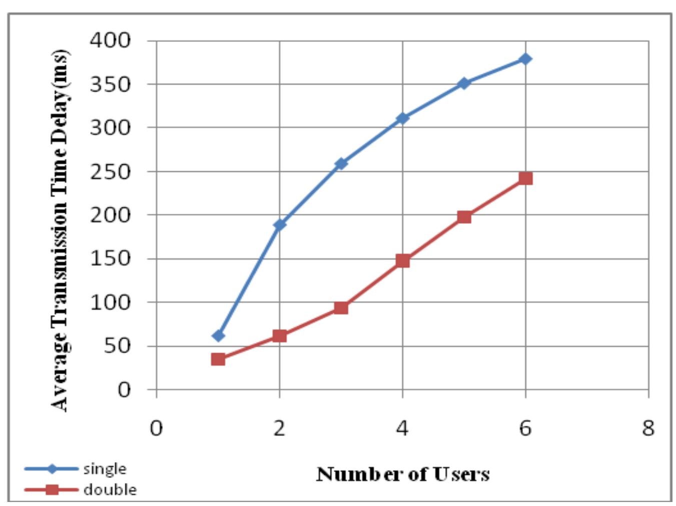

Figure 6. Packet transmission time delay vs. number of users for single and double line topologies

B. *Analysis based on Number of Nodes*

The performance of the simulated MSS network was evaluated in this study when the number of nodes between the source and destination was varied in both single line and double line topologies. Figure 7 shows the throughput of the network (in bps) versus the number of nodes. There are two plots, each corresponding to a different network topology. For each topology, the throughput of the network traffic decreases with an increase in the number of nodes. The most likely explanation for this is because the probability of packet error increases with an increase in the number of nodes between the source and the destination, thereby causing the network throughput to decrease.

It also can be seen from Figure 7 that the throughput when using double line topology is greater by 2.72% than the throughput for single line topology, and that the throughput difference between the two topologies starts to increase with an increase in the number of nodes between the source and destination.

Figure 8 shows that using double line topology will decrease the number of lost packets by 29.6% over using single line topology. In single line topology, the breakage of any link within the path will push the MAC layer to discard all packets for all users, as there is no other path available. Until the routing agent repairs the link again, the path remains unavailable so that the number of lost packets necessarily increases. On the other hand, when a link breakage occurs in double line topology, the MAC layer of the intermediate node will discard only the packets directed to the destinations affected by the link breakage, which makes the total number of lost packets less.

Figure 9 confirms that the Packet Transmission Ratio (PTR) is better in double line topology than in single line topology because the packet loss in double line topology is less than the loss in single line topology.

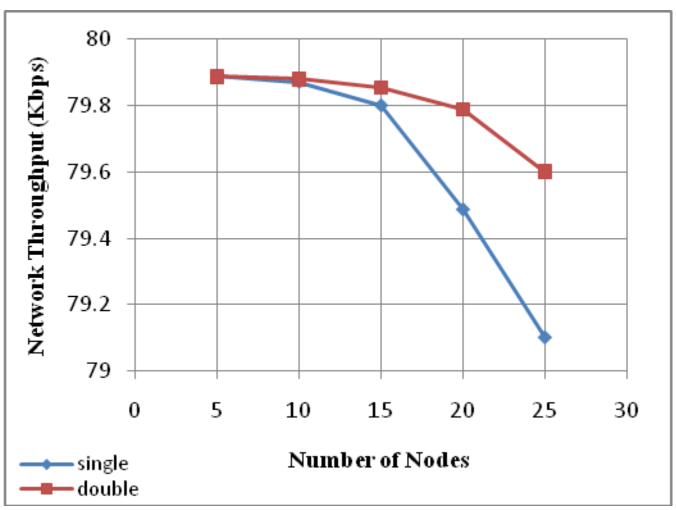

Figure 7. Network throughput vs. number of nodes for single and double line topologies

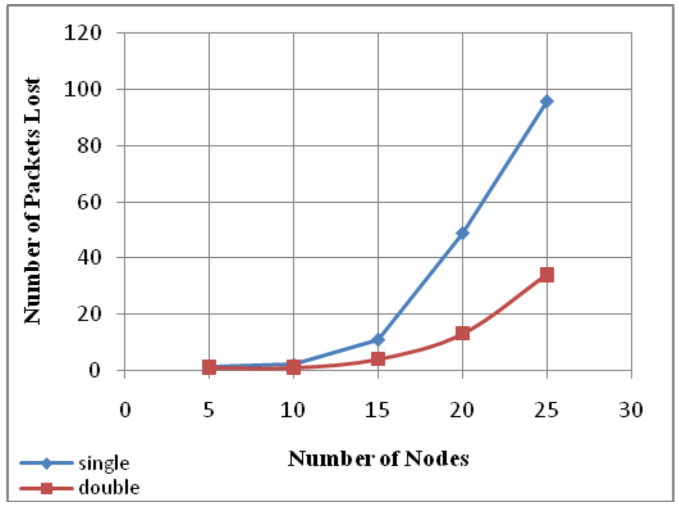

Figure 8. Number of lost packets vs. number of nodes for single and double line topologies

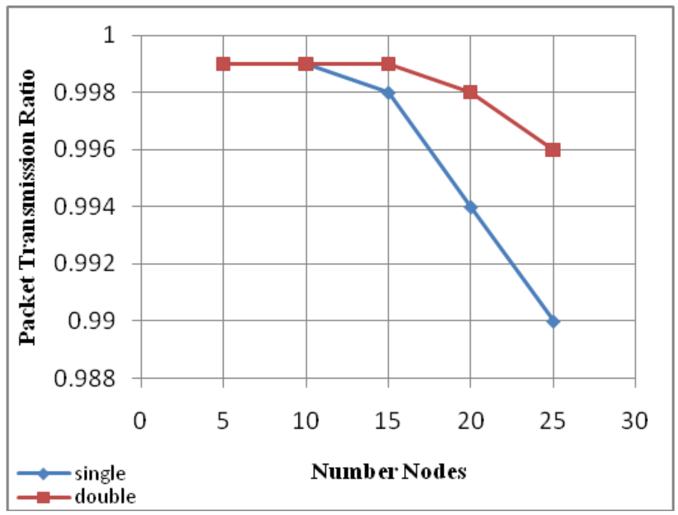

Figure 9. Packet transmission ratio vs. number of nodes for single and double line topologies

Figure 10 depicts the transmission time delay versus the number of nodes between the source and destination for the two different topologies. The transmission time delay in single line topology is greater when compared to the transmission time delay in double line topology. This result is likely because the channel contention in single line topology is higher than in double line topology, therefore any node in a single line topology will need more time to transmit its packets.

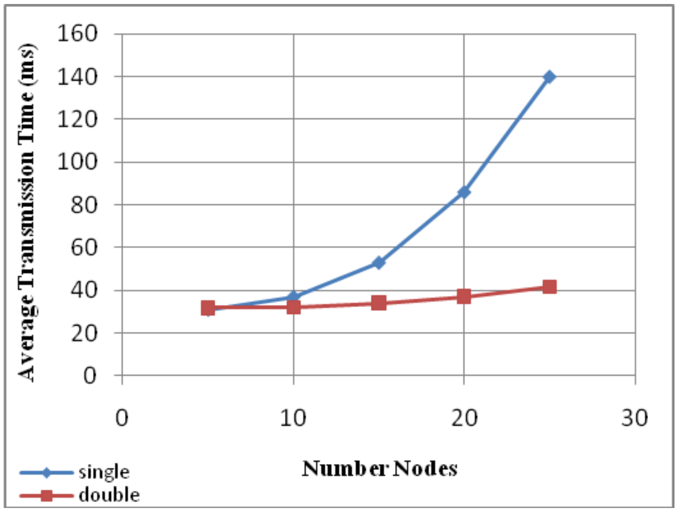

Figure 10. Packet transmission time delay vs. number of nodes for single and double line topologies

VI. Conclusion

The topology of the cameras network of the MSS is one of the most important parameter that may affect the performance of this system. Since the topology imposes several constraints on the amount of data that can be transmitted or received through the network, which leads to effects on the network's overall performance. This paper evaluates and analyzes the effects of topology on the performance of a motorway surveillance system comprised of wireless cameras placed along a roadway. Both single line and double line topology configurations could be used in a design for a motorway surveillance system with varying results.

This paper presents a comparison between both topologies (single and double line) that can be used in a motorway surveillance system. It can be concluded from the results of the experiments and their analyses that using double line topology is more preferable than using single line topology since the network throughput and packet transmission ratio in double line topology is better as compared to single line topology. Moreover, the distribution of the camera nodes of the surveillance system on both sides of a motorway in a double line topology will give the routing agent the ability to find multiple paths between the sources and destinations. This leads to better network throughput, a better packet transmission ratio. The use of multiple paths also results in a decreased number of lost packets and shorter transmission time delays.

Based on the results obtained from this study, the authors recommend using double line topology for a motorway surveillance system network as it can be expected to give better network performance and the results of the two experiments described in this paper demonstrate that faster access to data will be provided using the double line topology. A double line topology will also provide better coverage for the area under monitoring.

References

[1] W.-T. Chen, P.-Y. Chen, W.-S. Lee and C.-F. Huang, "Design and implementation of a real time video surveillance system with wireless sensor networks," in Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE, May 2008, pp. 218–222.

[2] L. A. Hassnawi, R.B Ahmad, Abid Yahya, M. Elshaikh, Ali Al-Rawi, Z. G. Ali, "Performance Analysis of Motorway Surveillance System Based on Wireless Ad Hoc Camera Network (WAHCN)", Journal of Communications and Information Sciences(JCIS), Volume 2. Number 1. April. 2012, pp.59-67.

[3] Mantzel, W. E., Hyeokho, C., & Baraniuk, R. G., "Distributed camera network localization", Paper presented on the Conference Record of the Thirty-Eighth Asilomar Conference at Signals, Systems and Computers, 2004, Vol.2, pp1381 – 1386.

[4] Hoydis, J., Petrova, M., & Mahonen, P., "Effects of topology on local throughput-capacity of ad hoc networks", Paper presented at the Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on. . (2008, 15-18 Sept. 2008).

[5] Shie-Yuan, W., Chih-Che, L., & Chao-Chan, H. "The effects of underlying physical network topologies on peer-to-peer application performances", Paper presented at the Personal Indoor and Mobile Radio Communications (PIMRC), 2010 IEEE 21st International Symposium on Sept. 2010.

[6] Lobaton, E., Vasudevan, R., Bajcsy, R., & Sastry, S., "A Distributed Topological Camera Network Representation for Tracking Applications", Image Processing, IEEE Transactions on, Vol.19 (10), pp2516-2529, 2010.

[7] Detmold, H., van den Hengel, A., Dick, A., Cichowski, A., Hill, R., Kocadag, E., et al., "Topology Estimation for Thousand-Camera Surveillance Networks", Paper presented at the Distributed Smart Cameras, First ACM/IEEE International Conference (ICDSC), 2007, pp195-202.

[8]Varga A. "Using the OMNET++ discrete event simulation system" European Simulation multiconference (ESM'01) Prague, Czech Republic,2001, june.

[9] Cisconet, "Internet Speed Issue - Bandwidth VS. Throughput." Novemeber 2009, available online: http://cisconet.com.

[10] J. Harri et al, 2007, "On Meaningful Parameters for Routing in VANETs Urban Environments under Realistic Mobility Patterns." 2007 Eurecomm Seminar Series, Sophia-Antipolis, France, 18 January 2007, available online.