Performance Analysis of Various Routing Protocols for Motorway Surveillance System Cameras' Network

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Abstract

The Motorway Surveillance System (MSS) is one of the most important technologies used to collect information about road conditions and then provide that collected information to motorway users. The routing in networks used by these systems is a critical task due to the highly dynamic environments. This paper presents performance evaluations, comparisons, and analysis for three routing protocols (AODV, DSR, and OLSR) on a selected MSS scenario. The evaluation and analysis were performed for several different performance metrics and under varying network conditions. The results demonstrate that, under various vehicle speeds and several different traffic loads, AODV outperforms DSR and OLSR protocols, with respect to network throughput (by 36.7% and 9.1%, respectively) and protocol overhead (by 23% and 45.2%, respectively). In contrast, the packet transmission delay when using DSR is shorter than when using AODV (by 26.7%) and OLSR (by 17.1%). The conclusions of this study are important to provide a qualitative assessment of the applicability of these protocols to real-world motorway surveillance systems, and also as a basis for developing new ways to improve routing performance in this type of systems.

Keywords: *AODV, DSR, Link Breakage, OLSR, Surveillance System, Throughput***.**

1. Introduction

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

The transmission range for a wireless radio, however, is typically limited to 200–300 meters outdoors and is much shorter indoors [1]. Therefore, to send the data of images from cameras deployed over a large area back to the requester of images, the cameras must both collect local images and also serve to relay images from other cameras towards the requester.

In the traditional Motorway Surveillance System (MSS) which uses infrastructure wireless network, the system is designed to send information to a predetermined location (the "Base Station") for processing and monitoring, or else to Gateway Points which then send all the information to the Base Station [2]. One design flaw that needs improvement is that the traditional system does not provide fully effective access to the MSS's network for the users of the motorway. For example, not all vehicles have access to the Base station or the Gateway Points in situations in which the distance between the vehicle and the gateway is too far, thus the need to add more base stations.

Our previous work [3] evaluated the design of a new type of MSS. The proposed system has a new image acquisition technique to enable the motorway user (the drivers of vehicles) to access this system by requesting images from any camera within the network while driving the vehicle, in order to view the road conditions without using any additional infrastructure or centralized administration.

The new system consists of a large number of IP cameras. These cameras are distributed along the motorway and are connected with each other to form a new type of network which we have called the Wireless Ad Hoc Camera Network (WAHCN) [3]. The operation of WAHCN is based on the operations of the Mobile Ad Hoc networks (MANETs); therefore, it inherits all the features of the MANETs. The nodes within the WAHCN are divided into two types: mobile nodes (vehicles) and stationary nodes (cameras). Stationary cameras have a limited range, therefore, to transmit the data (images) to mobile vehicles which are not in the sending camera's transmission range; the data must be forwarded through the network using other cameras which will operate as routers delivering the data throughout the network. All the nodes in the WAHCN are individually responsible for dynamically discovering other nodes in order to communicate. It is a self-configuring network of mobile and stationary nodes connected by wireless links, the union of which forms an arbitrary topology which may change rapidly due to the mobility of vehicles.

Many parameters affect the performance of the MSS's camera network, and the most important parameter is the performance of the routing protocol. Routing is a core problem in networks for sending data from one node to another. In a motorway surveillance system network, there is no fixed topology due to the vehicle mobility which leads to link breakage and path loss [4]. Therefore, the routing protocol plays a very important role that affects the network's performance of the MSS.

Different types of routing protocols give different network performances. These differences arise due to the different mechanisms of these protocols. Therefore the objective of this paper is to analyze, evaluate, and compare different routing protocols on MSS. Many parameters need to be taken into consideration when evaluating and analyzing the performance of routing protocols, such as network topology, density of nodes, node speeds, and network traffic load.

The main contributions of this paper are to evaluate, analyze, and compare the performance of three types of routing protocols: Ad Hoc on Demand Distance Vector routing protocol (AODV), Dynamic Source Routing protocol (DSR), and Optimized Link State Routing protocol (OLSR), as they are used on Motorway Surveillance System scenarios for different performance metrics. The performance evaluation and analysis of the routing protocols (AODV, DSR, and OLSR) is carried out under different network conditions in order to find the best routing protocol which is the most suitable for this type of system and also to find how to improve the routing performance within the system.

The remainder of this paper is organized as follows: Section 2 presents the related work of other authors. Section 3 describes the types of routing protocols used in mobile Ad Hoc networks. Section 4 presents a theoretical comparison between AODV, DSR, and OLSR. Section 5 presents the simulation scenario, model setup, and performance metrics. Section 6 presents the results and discussion. Finally, Section 7 concludes the paper.

2. Related Work

Many studies have been undertaken to analyze and evaluate the performance of different routing protocols for different types of networks and under various mobility patterns. This section surveys the most pertinent studies presented in recent years.

Julian et al. [5] studied the performance of the most common mobile ad hoc network protocols. They used four-hour simulations with 19 mobile nodes and a base station with different traffic categories generated to measure the qualitative and quantitative metrics. They used the default parameter settings for each protocol. The conclusion of their paper was that the AODV protocol performed the best, with slight advantages in overall throughput and lower overall delay per packet. OLSR, too, showed good performance with constantly changing hosts such that the network structure is ever-changing.

Toa et al. [6] presented an analytical model for comparing the overhead of AODV and OLSR protocols. The analytical model showed that the AODV protocol may suffer large overhead when establishing those routes in the network with high mobility which necessitates retransmission of the packets in the poor communication environment. In the case with OLSR, the study showed that the overhead is independent of the traffic profiles, so it has a fixed upper boundary for the overhead in a network regardless of the network's traffic.

Clausen et al. [7] evaluated AODV, DSR and OLSR in varying network conditions (node mobility, network density) and with varying traffic conditions (TCP, UDP). Their evaluation showed that unlike the findings of previous studies, OLSR performs comparatively well against the reactive protocols.

Tamilarasan et al. [8] presented a logical survey of routing protocols and compared the performances of the AODV, DSR, DSDV and OLSR routing protocols.

Broch et al. [9] compared the performance of AODV, DSDV, DSR and TORA and introduced some standard metrics that were then used in further studies of wireless routing protocols.

Gowrishankar et al. [10] compared the performance of two prominent routing protocols in MANET: the Ad hoc On-Demand Distance Vector Routing (AODV) and the Optimized Link State Routing (OLSR) protocol. The performance differentials were analyzed using various metrics. The comparison showed that the OLSR protocol is more efficient in networks with high density and highly sporadic traffic. Moreover, this comparison illustrated that the AODV protocol will perform better in the networks with static traffic, when the number of source and destination pairs is relatively small for each host.

Jaap et al. [11] compared AODV, DSR, FSR and TORA on highway scenarios, while in [12] compared the same protocols in city traffic scenarios. They found, for example, that AODV and FSR are the two best suited protocols, and that TORA or DSR are completely unsuitable for Vehicular Network (VANET).

Santos et al. [13] compared a position-based routing protocol (LORA) with the two non-position-based protocols, AODV and DSR. Their conclusions were that although AODV and DSR perform almost equally well under vehicular mobility, the location-based routing schema provides excellent performance.

Based on a survey of earlier studies, the authors of this research paper chose to concentrate on the evaluation, analysis, and comparison of two On Demand/Reactive Protocols (AODV, DSR) and one Table Driven/Proactive protocol (OLSR). The evaluations and analyses are performed on motorway surveillance system scenarios (freeway mobility pattern) for different performance metrics and under various operating conditions, in order to find the best routing protocol for this type of systems and also to find ways to improve routing performance under a variety of conditions.

3. Routing Protocols in Mobile Ad Hoc Networks

A MSS which is based on an infrastructure-less wireless network (Ad Hoc networks) inherits all the features of this type of networking, therefore the routing protocols which are used for wireless Ad Hoc networks can be implemented to study this type of system (MSS).

There are different criteria for classifying routing protocols for wireless Ad Hoc networks. Routing protocols are classified into two major types based on how and when routes are discovered: proactive or table driven, and reactive or on-demand.

In the proactive routing protocols, each node keeps its routing table updated with the route to each node in the network -- whether it needs it or not -- by sending control messages periodically between the hosts which update their routing tables. In proactive routing, each node has one or more routing tables that contain the latest information on the routes to any node in the network. The proactive routing protocols are based on either link-state or distance vector principles to maintain routes to every node in the network [14]. An example of proactive routing protocol is the Optimized Link State Routing Protocol (OLSR).

On the other hand, reactive routing is also known as an on-demand routing protocol since the nodes search routes to needed nodes only. Reactive protocols do not maintain routing information or routing activity at the network nodes if there is no communication. If a node needs to send a packet to another node, then the reactive protocol starts the route discovery operation in an on-demand manner, and when the route is established, the source node starts to send its packets via the established route to the destination. The route discovery usually occurs by flooding route request packets throughout the network. Examples of reactive routing protocols are the Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector routing (AODV). The next sub-section describes the basic features of these protocols. For a more detailed description, the reader is referred to the respective RFCs.

3.1. Ad Hoc on Demand Distance Vector Routing Protocol (AODV)

The Ad Hoc On-Demand Distance Vector Protocol (AODV) is an IP routing protocol that allows users to find and maintain routes to other users in the network. AODV is “on-demand” or “reactive” since the routes are established only when needed. The routing decisions are made using distance vectors, i.e. distances measured in hops to all available routers. The protocol supports unicast, broadcast, and multicast [15]. Each node maintains a sequence number which saves a time stamp, and a routing table which contains routes to destinations. Sequence numbers are used to determine the freshness of routes (the higher the number, the fresher the route which allows the older one to be discarded). The routing table consists of a number of entries (one entry per destination is allowed). Each table entry contains the address of the next hop (next node to the destination), a hop count (number of hops to the destination) and a destination sequence number. Since this is an on-demand distance vector scheme (routers maintain distances of only those destinations that they need to contact or relay information to). Each active route is associated with a lifetime stored in the table; after this time has passed, route timeout is triggered, and the route is marked as invalid and later on, removed. AODV can deal with any kind of mobility rate and a variety of data traffic. The two main mechanisms used by the AODV protocol to establish and maintain the connection between any pair of nodes are as follows:

1. Route Discovery mechanism.
2. Route Maintenance mechanism.

Fig. 1 shows the mechanisms of the AODV routing protocol.

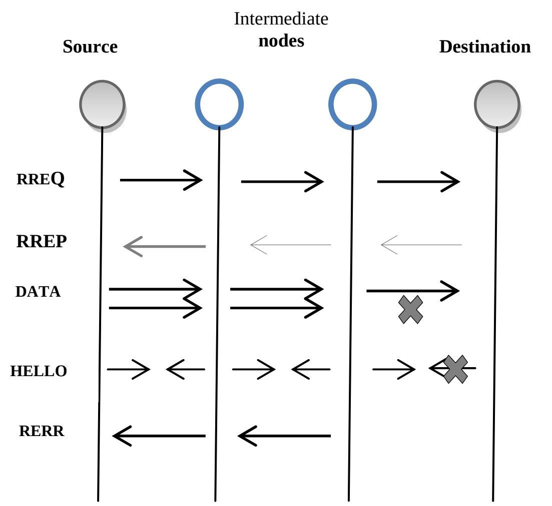

Fig. 1 AODV Mechanisms

3.1.1. Route Discovery Mechanism in AODV

If a sender (source node) needs a route to a destination, it broadcasts a ROUTE REQUEST (RREQ) message. Every node also maintains a broadcast id which, when taken together with the originator's IP address, uniquely identifies a RREQ. Every time a sender issues a RREQ, it increments its broadcast id and sequence number by one. The sender buffers this RREQ for PATH DISCOVERY TIME (PDT) so that it does not reprocess it when its neighbors send it back. The sender then waits for NET TRAVERSAL TIME (NETT) for a ROUTE REPLY (RREP). If a RREP is not received within this time, the sender will rebroadcast another RREQ up to RREQ TRIES times. With each additional attempt, the waiting time (NETT) is doubled.

When a node receives a RREQ message it has not seen before, it sets up a reverse route back to the node where the RREQ came from. This reverse route has a lifetime value of ACTIVE ROUTE TIMEOUT (ART). The reverse route entry is stored along with the information about the requested destination address.

If the node that receives this message does not have a route to the destination, it rebroadcasts the RREQ. Each node keeps track of the number of hops the message has made, as well as which node has sent it the broadcast RREQ. If nodes receive a RREQ which they have already processed, they discard the RREQ and do not forward it. If a node has a route to the destination, it then replies by unicasting a RREP back to the node it received the request from. The reply is sent back to the sender via the reverse route set by the RREQ. The RREP propagates back to the source; nodes set up forward pointers to the destination.

Once the source node receives the RREP, the route has been established and the source starts to send data packets to the destination. AODV includes an optimization mechanism to control the RREQ flood in the route discovery process. It uses an expanding ring search initially to discover routes to an unknown destination. In the expanding ring search, increasingly larger neighborhoods are searched to find the destination. The search is controlled by the TTL field in the IP header of the RREQ packets. If the route to a previously known destination is needed, the prior hop-wise distance is used to optimize the search [16, 17].

3.1.2. Route Maintenance Mechanism in AODV

As mentioned in [15], the role of route maintenance is to provide feedback to the sender in case a link breakage occurs, to allow the route to be modified or re-discovered. A route can stop working simply because one of the mobile nodes has moved. If a source node moves, then it must rediscover a new route. If an intermediate node moves, it must inform all its neighbors that may need this hop. This new message is forwarded to all the other hops and the old route is deleted. The source node must then re-discover a new route or else the node upstream of that break may choose to repair the link locally if the destination was no farther than MAX_REPAIR_TTL hops away.

To repair the link break, the node increments the sequence number for the destination and then broadcasts a RREQ for that destination. One proposed way for a node to keep track of its neighbors is by using HELLO messages. These are periodically sent to detect link failures. Upon receiving notification of a broken link, the source node can restart the rediscovery process. If there is a link breakage, a ROUTE ERROR (RERR) message can be broadcast on the net. Any host that receives the RERR invalidates the route and rebroadcasts the error messages with the unreachable destination information to all nodes in the network.

3.1.3. Advantage and Disadvantage of AODV

Table 1 reviews the advantages and disadvantage of AODV routing protocol.

Table 1: AODV Advantages and Disadvantages

	AODV Advantages	*AODV Disadvantages*
1	AODV can respond very quickly to the topological changes that affect the active routes, because of its adaptability to highly dynamic networks.	A large number of control packets are generated when a link breakage occurs. These control packets increase the congestion in the active route.
2	AODV can support both unicast and multicast packet transmissions, even for nodes in constant movement.	AODV has a high processing demand.
3	AODV has lower setup delay for connections and detection of the latest route to the destination [18].	AODV consumes a large share of the bandwidth.
4	AODV does not put any additional overheads on data packets as it does not make use of source routing.	AODV takes long time to build the routing table.
5	AODV protocol is a flat routing protocol. It does not need any central administrative system to handle the routing process.	It is possible that a valid route may have expired and the determination of a reasonable expiry time is difficult.
6	AODV is loop-free, self-starting, and scales to a large number of mobile nodes.	As the size of the network grows, various performance metrics begin decreasing.
7	If the source later receives a RREP containing a greater sequence number or contains the same sequence number with a smaller hop count, it may update its routing information for that destination and begin using the better route.	Multiple RREP packets in response to a single RREQ packet can lead to heavy control overhead and the periodic beaconing (hello message) leads to unnecessary bandwidth consumption. Also very high overhead since data packets may be delivered to too many nodes which do not need to receive them.

3.2. Dynamic Source Routing (DSR) Protocol

Dynamic Source Routing (DSR) is a reactive, on-demand routing protocol for wireless Ad Hoc networks and is based on a method known as source routing [19], that is, the sender knows the complete hop-by-hop route to the destination. Nodes in a DSR broadcast route request on on-demand bases if the node does not have the required route in its routing table. Nodes in DSR 'learn' and cache multiple routes to each destination (either as a response to a request, forwarding, or overhearing) to be used in case of route loss. In addition, this also helps in reducing routing overheads. The on-demand feature of DSR reduces the bandwidth use, especially in cases where the mobility is low [19]. Several additional optimizations have been proposed such as:

1. Salvaging: An intermediate node can use an alternate route from its own cache, when a data packet meets a failed link on its source route.
2. Gratuitous route repair: A source node receiving a RERR packet piggybacks the RERR on the following RREQ. This helps clean up the caches of other nodes in the network that may have the failed link in one of the cached source routes.
3. Promiscuous listening: When a node overhears a packet not addressed to it, it checks if the packet could be routed via itself to gain a shorter route.

The DSR uses two main mechanisms: Route Discovery and Route Maintenance, which work together to enable nodes to discover routes to destinations, and to maintain the routes to prevent any loss [19].

3.2.1. Route Discovery Mechanism in DSR

In DSR, the route discovery mechanism follows a set of steps to determine the best route. When, say, node "S" utilizing DSR has a data packet to transmit to node "D", as shown in Fig. 2, it checks its routing table to find the route to the destination from the route that has already experienced route cache, and adds to the packet header the sequence of nodes that the packet should be routed through. If no route is found to the destination, then node "S" activates the route discovery procedure to find the route to the destination, node "D". When the route discovery procedure is activated, it broadcasts a route request message that can be received by all nodes within the transmission range of the requester (node "S"). This route request message carries the ID of the requester (node "S"), the destination, node "D", a list of all of the intermediate nodes that the request message has passed through, and the request message's ID (the request message ID is assigned by the request initiator), by which old and new requests can be distinguished.

The requester source (node "S") sends an empty list of intermediate nodes. Each intermediate node appends its ID to the request message before re-transmitting it until the request reaches the requested node "D". Fig. 2 shows an example of route requesting for DSR nodes. When the destination, node "D", receives the route request, it checks its cached routes to find a better route to the request initiated by "node S". If it finds a route in its cached routes, then it sends a route reply to the request initiator using the source routing mechanism, otherwise it uses the reverse of the route that has been used by the request message to send the reply[19].

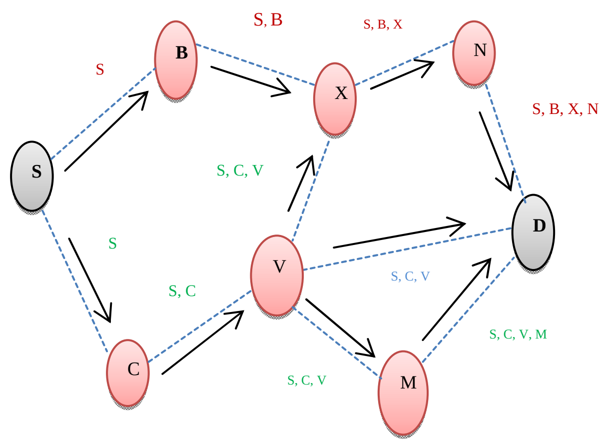

Fig. 2 Route discovery mechanism in DSR

3.2.2. Route Maintenance Mechanism in DSR

Once the route is established between the source (node “S”) and the destination (node “D”), the source starts sending data through the route. The data packets are acknowledged hop-by-hop through the routes. These acknowledgements can be link-layer acknowledgements, passive acknowledgements or network-layer acknowledgements specified by the DSR protocol. If no acknowledgement is received by any node on the route, then the node re-transmits the packet until acknowledgement is received, or until the maximum number of re-transmissions is reached. If the maximum number of re-transmissions is reached and no acknowledgement is received, the node which experienced the maximum number of transmissions considers the route to be broken, and has to inform the source about the route breakage by sending a route error message. When the source node is informed about the route breakage, it removes the broken route from its cache and starts repairing the route to the destination by looking for another route in its cached routes. If no route is found to the destination, then the source starts a new route discovery mechanism.

3.2.3. Advantages and Disadvantages of DSR

Table 2 reviews the advantages and disadvantage of DSR routing protocol.

Table 2: DSR Advantages and Disadvantage

	DSR Advantages	***DSR Disadvantages***
1	No need to keep a routing table inside each node because the entire route is contained in the packet header of each data packet sent from the source to the destination.	DSR is not scalable to large networks and requires significantly more processing resources than most other protocols.
2	DSR allows multiple routes to any destination and allows each sender to select and control the routes used in routing its packets, for example, for use in load balancing or for increased robustness.	Each node must spend a lot of time to process any control data it receives in order to obtain the routing information, even if it is not the intended recipient.
3	DSR protocol includes easily guaranteed loop-free routing, operation in networks containing unidirectional links, use of only "soft state" in routing, and rapid recovery when routes in the network change.	Route maintenance mechanism does not locally repair a broken link.
4	A node processes a route request packet only if it has not already seen the packet and its address is not present in the route record of the packet. This minimizes the number of route requests propagated in the network.	Stale route cache information could also result in inconsistencies during the route reconstruction phase because an intermediate node may send a Route Reply using a stale cached route, thus polluting other caches.
5	An intermediate node can use an alternate route from its own cache, when a data packet meets a failed link on its source route.	The connection setup delay is higher than in table-driven protocols.
6	DSR does not enforce any use of periodic messages from the mobile hosts for maintenance of routes.	Even though the protocol performs well in static and low-mobility environments, the performance degrades rapidly with increasing mobility.
7	DSR enables multiple routes to be learnt for a particular destination. DSR does not require any periodic update messages, thus avoiding wastage of bandwidth.	Routing overhead is involved due to the source-routing mechanism employed in DSR. This routing overhead is directly proportional to the path length and data load.
8	Route caching can further reduce route discovery	A flood of route requests may potentially reach all

	overhead.	nodes in the network.
9	A single route discovery request may yield many routes to the destination, due to intermediate nodes replying from local caches.	Increased contention if too many route replies come back due to nodes replying using their local cache—a Route Reply Storm problem. A reply storm may be eased by preventing a node from sending a RREP if it hears another RREP with a shorter route.

3.3. Optimized Link State Routing Protocol (OLSR)

The information in this section concerning the Optimized Link State Protocol is taken from its RFC standard [20]. Optimized Link State Routing protocol (OLSR) was developed for mobile ad hoc networks. It is a table-driven proactive routing protocol so the routes are always immediately available when needed.

OLSR is an optimization of link-state routing. In a classic link-state algorithm, link-state information is flooded throughout the network. OLSR uses this approach as well, but the message flooding in OLSR is optimized to preserve bandwidth. The optimization is based on a technique called Multipoint Relaying. The nodes are free to organize themselves arbitrarily, move randomly, and treat each mobile host as a router. Under this protocol, all the nodes contain pre-computed route information about all the other nodes in network. This information is exchanged by protocol messages periodically.

OLSR performs hop-by-hop routing, whereby each node uses its most recent topology information for routing. Each node selects a set of its neighbor nodes as Multi Point Relays (MPRs). Only those nodes selected as MPRs are responsible for forwarding the Control Traffic. MPRs are selected such that 2-hop neighbors can be reached through at least one MPR node. OLSR provides shortest path routes to all destinations by providing link-state information for their MPR selectors. Nodes which have been selected as MPRs by some neighbor nodes announce this information periodically in their Control Messages. MPRs are used to form the route from starting node to destination node in MANET. All this information is announced to neighboring MPRs through Control Messages. The purpose of selecting MPRs is to reduce flooding overhead and provide optimal flooding distance as shown in Fig. 3.

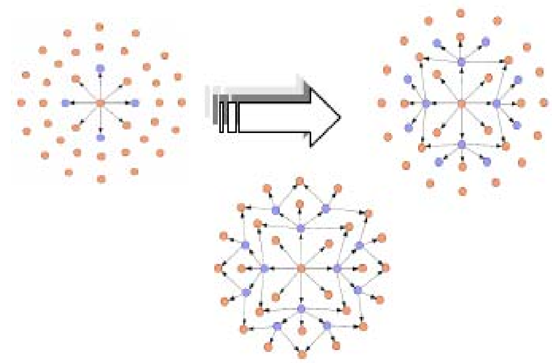

Fig. 3 Node selection of MPR

OLSR uses two kinds of control messages: Hello and Topology Control (TC). Hello messages are used for finding information about the link status and the host's neighbors. With the Hello message, the Multipoint Relay (MPR) Selector set is constructed which describes which neighbor has chosen this host to act as MPR. From this information, the host can calculate its own set of the MPRs. The Hello messages are sent only one hop away but the TC messages are broadcast throughout the entire network. TC messages are used for broadcasting information about neighbors, which includes at least the MPR Selector list. The TC messages are broadcast periodically and only the MPR hosts can forward the TC messages.

There are a few parameters in OLSR which can control the efficiency of OLSR. The Hello-interval parameter represents the frequency of generating a Hello message. Increasing the frequency of generating Hello messages leads to more frequent updates about the neighborhood and hence a more accurate view of the network and result in overhead. The TC-interval parameters represent the frequency of generating a TC message and are used for topology discovery.

If the frequency of TC messages is increased, then nodes receive more recent information about topology, as nodes leave and enter in the network very frequently. The MPR-coverage parameter allows a node to select redundant MPRs. The number of MPRs should be kept at a minimum as it introduces overhead in the network. But the more the MPRs, the better is the reach-ability. The TC-redundancy parameter specifies for the local node the amount of information that may be included in the TC message. The TC-redundancy parameter affects the overhead through affecting the number of links being advertised as well as the number of nodes advertising links.

Through the exchange of OLSR control messages, each node accumulates information about the network. This information is stored according to the OLSR specifications. Timestamp records allow each data point to modify the control messages and local repositories accordingly. For better efficiency of OLSR, a variety of state information such as the residual energy level of each node, bandwidth, queue length, etc., should be available while making routing decisions. Incorrect information may lead to degradation in efficiency of OLSR.

3.3.1. Advantages and Disadvantages of OLSR

Table 3 reviews the advantages and disadvantage of DSR routing protocol

Table 3: OLSR Advantages and Disadvantages

	OLSR Advantages	*OLSR Disadvantages*
1	OLSR has less average end-to-end delay; therefore it is used for applications which need minimum delay.	OLSR Maintain the routing table for all the possible routes.
2	The OLSR implementation is more user-friendly and worked with fewer headaches than other protocols. OLSR is also a flat routing protocol; it does not need a central administrative system to handle its routing process.	When the number of mobile hosts increases, then the overhead from the control messages also increases.
3	OLSR increases the protocol's suitability for an ad hoc network with the rapid changes of the source and destinations pairs.	OLSR needs considerable time to re-discover a broken link.
4	OLSR protocol does not require that the link is reliable for the control messages, since the messages are sent periodically and the delivery does not have to be sequential.	OLSR requires more processing power than other protocols when discovering an alternate route.
5	The simplicity of the OLSR routing protocol in using interfaces is advantageous; it is easy to integrate the routing protocol into existing operating systems, without having to change the format of the header of the IP messages. The protocol only interacts with the host's Routing Table.	OSLR has a wider delay distribution than other protocols.
6	OLSR protocol is well suited for an application which does not allow long delays in the transmission of data packets.	OLSR constantly uses bandwidth.
7	OLSR protocol works most efficiently in dense networks, where the most communication is concentrated between large numbers of nodes.	The storage complexity of the OLSR protocols is related to how many hosts are in the network. The required storage increases with increasing network size.

4. Theoretical Comparison between AODV, DSR, and OLSR

From the survey mentioned above, a theoretical comparison of the characteristics of the three routing protocols -- AODV, DSR, and OLSR -- is given in Table 4.

Table 4: Protocols Comparison

Protocol Property	*AODV*	*DSR*	*OLSR*
Proactive	NO	NO	YES
Distributed	YES	YES	YES
Unidirectional Link	NO	YES	YES
Multicast	YES	NO	YES
Periodic Broadcast	YES	NO	YES
Routes Information Maintained in	Route Table	Route Cache	Route Table
Reactive	YES	YES	NO
Provide Loop-Free Routers	YES	YES	YES
Route Optimization	YES	YES	YES
Scalability	YES	YES	YES
Routing Philosophy	FLAT	FLAT	FLAT
Route Reconfiguration	Erase Route Notify Source	Erase Route Notify Source	Link State Announcement

5. Simulation Scenario

OMNeT++ ver. 4.1 [21] was used to model motorway surveillance system (MSS) scenarios as shown in Fig. 4. The model was designed with an extensive set of parameters and was used to evaluate, analyze, and compare the performance of three routing protocols (AODV, DSR, and OLSR). Table 5, shows the setup of parameters in a simulated scenario.

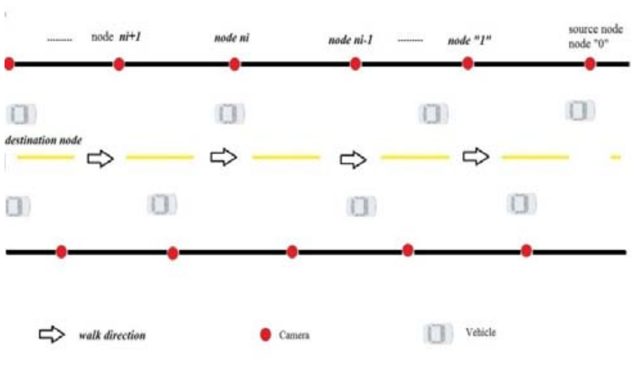

Fig. 4 Motorway Surveillance System Scenario

Table 5: Parameters Setup

Parameter name	***Value***
Playground	5000 m * 100 m
Number of camera nodes	40
Distance between camera nodes	250 m
Packet size	0.5KB
Packet rate	20 packet/s
Simulation time	500 s
Routing protocols	AODV,DSR, OLSR
Traffic Pattern	CBR,UDB
Radio bit rate	54 Mbps
Vehicle speed	10,20, 30, 40 and 50 meter/second
Mobility Model	Freeway Mobility

5.1. Motorway Model Setup

The performance evaluation of the routing protocols was done on the motorway scenario with the following model specifications:

- The simulation scenario is a 5-km straight motorway section with two lanes in one direction.
- 40 camera nodes are distributed along both sides of the motorway in a double line topology with 250 meter separations between each two cameras.
- Three vehicles are distributed on the lanes of the motorway and move in a freeway mobility pattern. The distance between each two vehicles is 50m.
- The vehicles' speeds are distributed between 36 km/h as the minimum speed and 150 km/h as the maximum speed.
- The size of data packet is 512 Bytes.
- The value of packet rate is selected to be 20 packets / second.
- All the cameras use UDP traffic sources with CBR traffic pattern.
- Data transfer rate is 54 Mbps.
- OMNET++ set at default parameters.
- All experiments tested for 500-seconds simulation time.
- All vehicles move according to the freeway (linear) mobility pattern.
- All the vehicles move toward the sources of data.

5.2. Performance Metrics

The metrics selected to evaluate the performance AODV, DSR, OLSR routing protocols are:

- Throughput – represents the average rate of successful packet delivery per unit time over a communication channel.
- Packet Loss -- represents the difference between the number of packets sent by the source node and the packets received at the destination node.
- Packet transmission ratio (PTR) -- represents the ratio between the numbers of packets received by the destination to the number of packets sent by the source.
- Protocol overhead -- represents total number of bytes and packets used for routing during the simulation.
- 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 arrives at the vehicle node. It includes all kinds of delays like queuing delay propagation delay, etc.

6. Results and Discussion

Two types of experiments were carried out to evaluate and analyze the impact of vehicle speed variations on the performance of two reactive routing protocols (AODV and DSR) and one proactive routing protocol (OLSR) by using single and multiple sources of data. Both experiments performed using MSS scenarios were made in order to compare between the performances of the above protocols in this type of system, and consequently, to find the best routing protocol for networks used for motorway surveillance. In addition, the experiments also were aimed at finding ways to improve the routing performance of MSS camera networks.

6.1. Throughput Evaluation

Fig. 5(a) shows the network throughput (in bps) versus the vehicle speed using a single source of data. There are three plots, each corresponding to a different routing protocol. For each protocol, the throughput of the network starts to decrease with an increase in the vehicle speed. Fig. 5(a) demonstrates that the throughput's decrease percentage is slight at about 3% when using the AODV routing protocol, and less than the throughput's percentage decrease when using other protocols (DSR, by about 28.2% and OLSR, by about 11.77%). This is because the AODV reacts relatively quickly to the topological changes in the network and updates only the hosts that may be affected by the change. Moreover, Fig. 5(a) shows that the performance of OLSR is better than DSR and less efficient than AODV.

Fig. 5(b) shows the network throughput (in bps) versus the vehicle speed when using multiple sources of data. This figure demonstrates that the performance of AODV outperforms the performance of the other two protocols (DSR and OLSR). While increasing the number of sources, DSR exhibits the highest drop in throughput. This is due to packets being dropped along outdated routes. Fig. 5(b) shows a big drop in throughput at a higher number of sources. This is an effect of the higher network load caused by the source routes carried in all data packets, therefore, at higher mobility and when using multiple sources of data, AODV and OLSR are more robust than DSR.

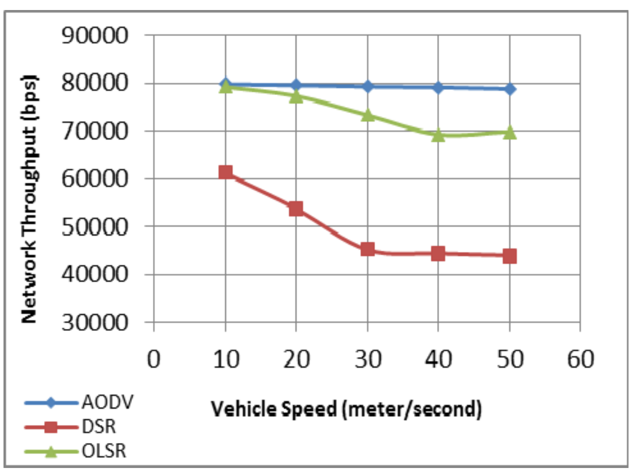

Fig. 5(a) Network throughput vs. vehicle speed using single data source

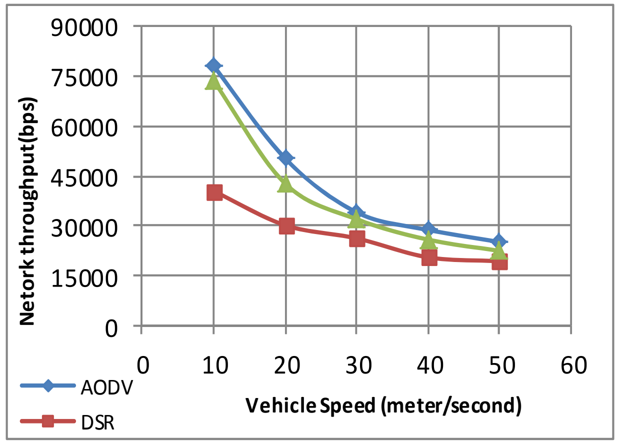

Fig. 5(b) Network throughput vs. vehicle speed using multiple data sources

6.2. Number of Packets Lost

Another important quality in communication is the packet loss performance of a network. It is influenced by many factors like routing protocol performance, interference, and channel conditions. Fig. 6(a) shows number of packets lost versus the vehicle speed when using a single source of data. There are three plots, each corresponding to a different routing protocol. Fig. 6(a) shows that the number of lost packets increases for all three routing protocols with an increase in the vehicle speed, because increasing vehicle speed will increase the probability of link breakage which leads to lost packets.

The number of lost packets when using DSR is larger than number of lost packets when using other protocols (AODV and OLSR). This is because the DSR cannot react quickly to recover the broken link, especially when there is no route in its cache to the unreachable destination. Also, DSR can only rediscover new routes to the unreachable destination by the source node (source routing) rather than the upstream node of the broken link performing a local repair. This leads to an increase in the number of lost packets.

Fig. 6(a) also shows that the AODV outperforms OLSR, as well as DSR. The OLSR reacts well to the link breakage because OLSR continuously maintains routes to all destinations in the network and when link break happens, it can find new route to the destination faster than DSR. On other hand, Fig. 6(b) demonstrates that the number of lost packets increases with increasing vehicle speed when using multiple sources of data for all three routing protocols. Increasing the number of sources means an increase in the amount of data pushed into the network;

at higher loads, the network drops a rather large number of packets due to buffer overflow in some congested nodes. This congestion is caused by an increase in MAC layer packet collisions, giving less capacity to drain queues, combined with a higher aggregated packet rate in some forwarding nodes. Fig. 6(b) shows that the number of dropped packets when using DSR is more than the number of dropped packets when using AODV or OLSR, because the source routes carried in all data packets. Thus, DSR will face a higher packet loss than AODV and OLSR when the amount of traffic load is increased.

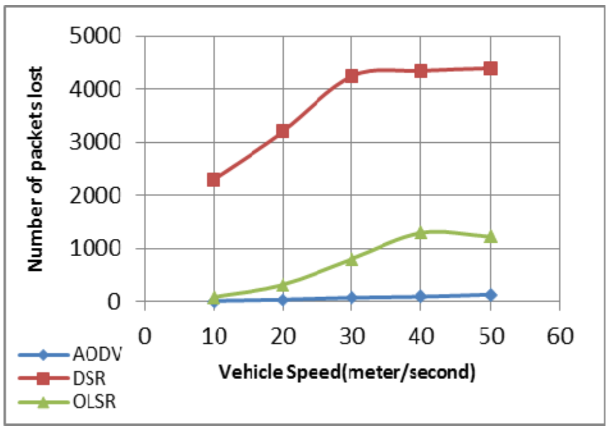

Fig. 6(a) Number of lost packets vs. vehicle speed using single data source

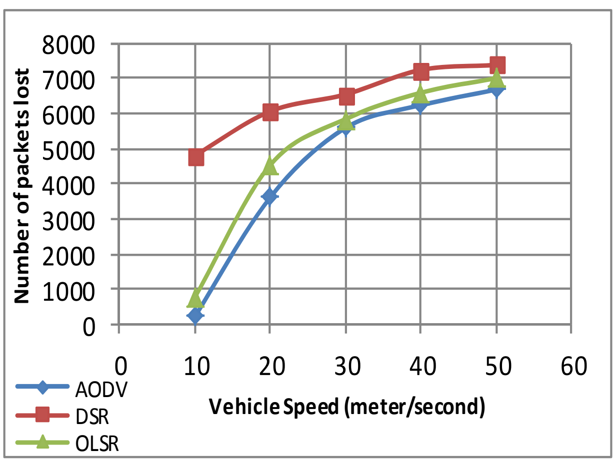

Fig. 6(b) Number of lost packets vs. vehicle speed using multiple sources of data

6.3. Packet Transmission Ratio (PTR)

Packet Transmission Ratio (PTR) describes the loss rate that will be seen by the transport protocols, which in turn affects the maximum throughput that the network can support. Fig. 7(a) demonstrates the PTR versus vehicle speed when using a single source of data. For each protocol, the network PTR starts to decrease with an increase in vehicle speed. Fig. 7(a) shows that the AODV performs well when using a single source of data as the traffic load will be less, and that the PTR decrease when using AODV is slight (about 0.32%), and less than the decrease when using other protocols (DSR, by about 7.75% and OLSR, by about 3.48%). This is because the AODV reacts relatively quickly to the topological changes in the network, consequently the number of lost packets will be small, and this makes the decrease in PTR only slight.

Moreover, Fig. 7(a) shows that the PTR of OLSR is better than DSR but less than AODV. This behavior is due to the reactive nature of OLSR. Fig. 7(b) shows that the PTR declines with increased vehicle speed and an increasing number of data sources for all three routing protocols. The decline, when using multiple sources of data, is larger than when using a single source of data. This can be expected because increasing the number of data sources means increasing the amount of data pushed to the network which leads, in turn, to more channel contention and packet collisions, therefore the number of lost packets will be high which correlates to a low PTR. Moreover, Fig. 7(b) shows that the OLSR outperforms DSR protocol in cases where vehicle speed is increases. The performance of DSR is consistently uniform.

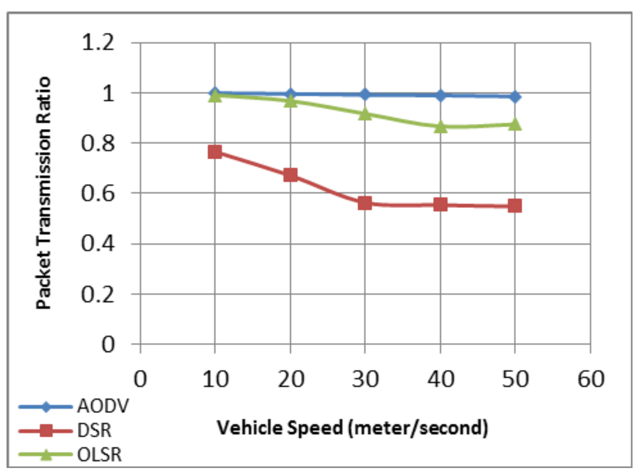

Fig. 7(a) Packet transmission ratio vs. vehicle speed using single data source

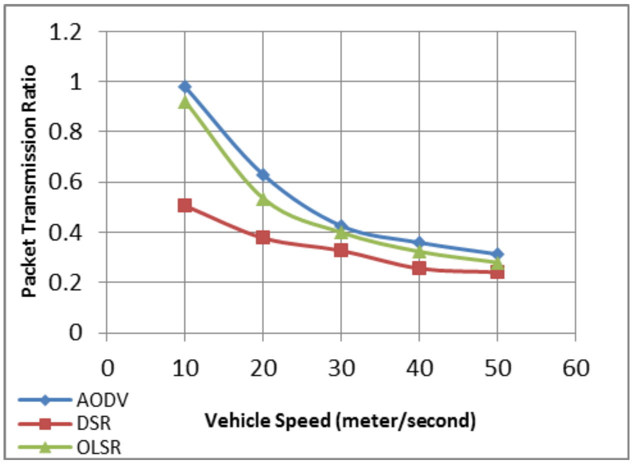

Fig. 7(b) Packet transmission ratio vs. vehicle speed using multiple data sources

6.4. Protocol Overhead

Protocol overhead represents total number of bytes generated by a routing protocol for routing operations within a network. Increased protocol overhead will negatively affect the network performance by consuming bandwidth. Fig. 8(a) shows protocol overhead versus the vehicle speed when using a single source of data. Fig. 8(a) demonstrates that the OLSR has the highest overhead. Because OLSR is a table-driven protocol, and the proactivity nature of OLSR makes it exchange topology information with other nodes of the network regularly and periodically, this increases the overhead. In contrast, the overhead of DSR is demonstrably lower than the overhead of AODV due to the way routes are detected in DSR; also the route acquisition procedure in DSR allows more routes to be detected and cached with the same RREQ than in AODV (which obtains a single route per RREQ), and this reduces the protocol overhead in DSR.

Fig. 8(b) shows the protocol overhead versus vehicle speed when using multiple sources of data. It demonstrates that the AODV overhead is lower than the overhead of OLSR and DSR. With an increase in the number of data sources, the OLSR overhead still remains higher than DSR and AODV, likely due to the proactive nature of OLSR. The overhead of DSR is higher than the overhead of AODV, likely because DSR is based on source routing algorithms and every data packet must hold the entire route from the source to the destination in its header which increases the DSR overhead.

Taken together, Fig. 8(a) and Fig. 8(b) demonstrate that the overhead of the three protocols decreases with increases in vehicle speed in both cases (single and multiple sources of data). This is likely because at low speeds, routes are relatively long lived. More traffic is carried over the same paths during longer times, so a longer route will form and incur higher overhead.

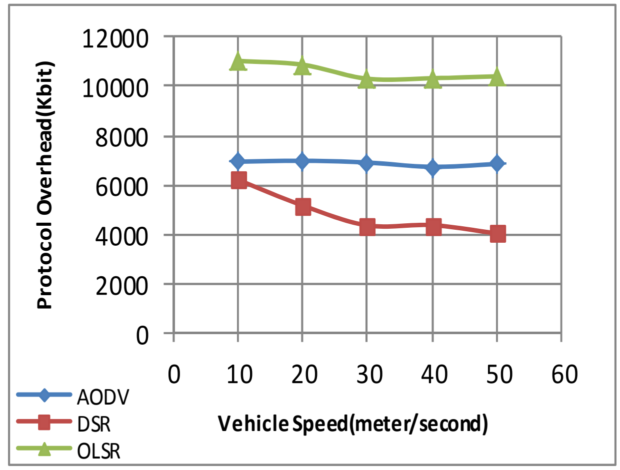

Fig. 8(a) Protocol overhead vs. vehicle speed using single data source

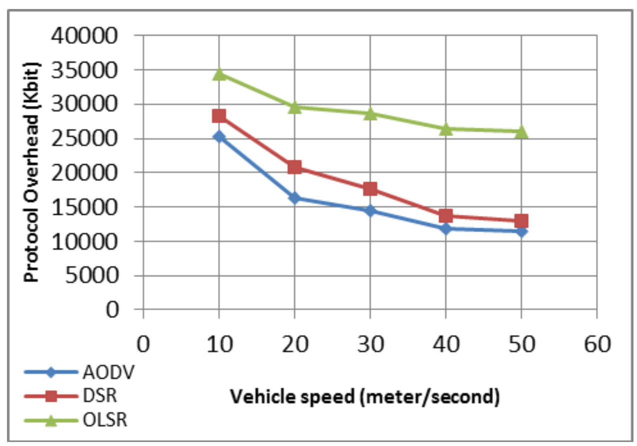

Fig. 8(b) Protocol overhead vs. vehicle speed using multiple sources of data

6.5. Packet Transmission Time Delay

The average packet transmission time delay increases with an increase in vehicle speed for all three protocols, as shown in Fig. 9(a). However, at a light traffic load, OLSR has a lower delay than DSR and AODV for all vehicle speed values. OLSR consistently presents the lowest delay, regardless of the amount of data traffic. This may be explained by the fact that OLSR, as a proactive protocol, has faster processing at intermediate nodes. When a packet arrives at a node, it can immediately be forwarded or dropped. In reactive protocols, if there is no route to a destination, packets to that destination will be stored in a buffer while a route discovery procedure is conducted which takes some time. Moreover, OLSR continuously maintains routes to all destinations in the network. When link break occurs, it can quickly find a new route to the destination since the routing table has routes for all available hosts in the network.

On the other hand, DSR has a lower delay than AODV for all speed values due to the way routes are detected in DSR. The route acquisition procedure in DSR allows more routes to be detected and cached than in AODV, which obtains a single route per RREQ. With DSR, packets wait less time during route acquisition than with AODV.

Fig. 9(b) shows that the average packet transmission time delays versus vehicle speed for all three routing protocols. All protocols exhibit higher delays when using multiple sources of data than when using single source of data. This is because the delay time is affected by the amount of data pushed into the network (offered load). The buffers become full much more quickly when using multiple sources of data, so the packets have to stay in the buffers for a longer period of time before they are sent. Fig. 9(b) also demonstrates that the packet transmission time delay of DSR is the lowest when compared to AODV and OLSR delays. This is likely because with a higher mobility and heavier traffic load, links are more frequently broken. Since routes are available in the cache of DSR, the route discovery procedure requires less time than the other protocols. The AODV discovers routes whenever a change in the topology is detected. In OLSR, routes are known well in advance; hence the average packet transmission delay is less than AODV.

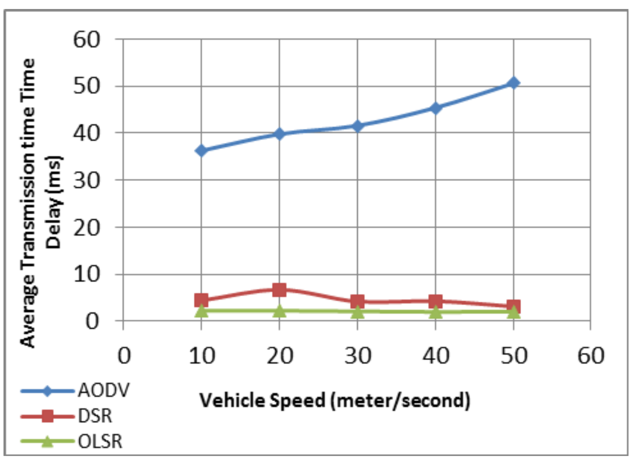

Fig.9 (a) Average transmission time delay vs. vehicle speed using single data source

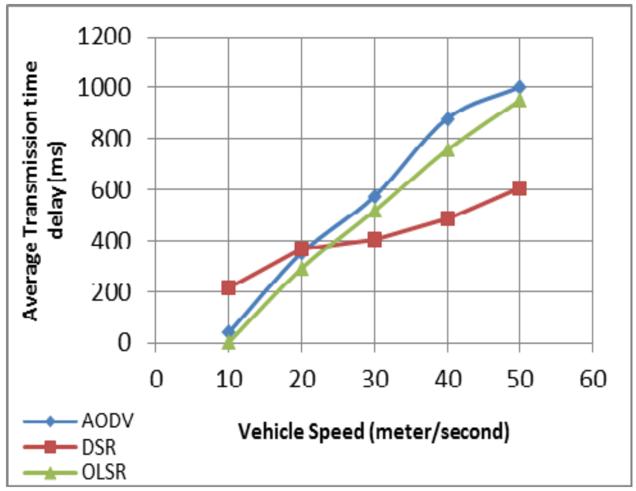

Fig.9 (b) Average transmission time delay vs. vehicle speed using multiple data sources

7. Conclusion

The network construction for a motorway surveillance system may be based on either a wireless network infrastructure or infrastructure-less wireless network (Ad Hoc network). In the MSS which is based on an infrastructure-less (Ad Hoc) network, the wireless links go down frequently. This is most likely due to the mobility of vehicle nodes as requesters of the images or for a variety of other reasons. In order to find the best protocol for this type of network and to find ways to improve the routing performance in motorway surveillance systems, this paper presents an evaluation, comparison, and analysis of three routing protocol (AODV, DSR, and OLSR) using a selected MSS scenario.

It can be concluded from the experimental results shown here that under varying vehicle speeds and with a varying number of data sources, the performance of the AODV routing protocol is better than the performance of DSR and OLSR routing protocols, with respect to network throughput, number of packets lost, packet transmission ratio, and protocol overhead. AODV may be considered "the best," given its ability to maintain connections by periodic exchange of information. AODV delivered virtually all packets even at different vehicle speed values. On other hand, DSR outperforms both AODV and OLSR with respect to packet transmission time delay at all speed values due to the way routes are detected in DSR. It can be seen that with DSR, packets wait less time during route acquisition than with AODV and OLSR. Table 6 demonstrates a practical comparison between the AODV, DSR, and OLSR protocols using the selected MSS scenario.

Table 6: Practical Comparison between Different Routing Protocols

Parameters	***AODV***	***DSR***	***OLSR***
Network Throughput	High	Low	Medium
Packets Delivered	High	Low	Medium
Protocol Overhead	Low	Medium	High
End-to–End Delay	High	Low	Medium
PTR	High	Low	Medium
Perform repair by inter-mediate nodes	Yes	No	Yes
Performance with increased offered load	Good	Poor	Acceptable
Performance with increases in vehicle speed	Good	Poor	Acceptable

In general, the results show that the on-demand reactive protocols are more efficient than proactive routing protocols in terms of control overhead on MSS, since routes are only established when required. By contrast, proactive protocols require periodic route updates to keep information current and consistent. However, many routes are maintained by proactive protocols which may never be needed, which significantly adds to routing overhead in the bandwidth-constrained network.

As routing overhead grows exponentially with network size, bandwidth constraints prevent the application of these protocols in large-scale networks (at the present time, given the technologies currently available). It is worth considering that proactive routing protocols generally provide a better quality of service than on-demand protocols (on the small scale). In proactive protocols, routes to every destination are always available and up-to-date, and, hence, end-to-end delay can be minimized. For on-demand protocols, the source node has to wait for the route to be discovered before communication can happen. This delay in route discovery might be unsuitable for real-time applications. Therefore, to improve routing performance in a motorway surveillance system, the protocol overhead must be reduced in order to reduce bandwidth consumption. Overhead reduction is considered to be a real advantage as it leads to a decrease in the packet transmission time delay and number of packets lost, while increasing the network throughput and packet transmission ratio. Therefore, the low protocol overhead measured experimentally for the AODV protocol can be considered a significant factor in developing new ways to improve real-world motorway surveillance systems.

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