Al Albayt University

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Department of Computer Science

SYSTEM LIFETIME-AWARE ROUTING PROTOCOL FOR MOBILE AD-HOC NETWORKS

خوارزمية لإيجاد المسارات في الشبكات الخاصة المتحركة اعتمادا على عمر النظام

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تفويض

أنا قدر عايد الخوالدة ، أفوض جامعة آل البيت بتزويد نسخ من رسالتي للمكتبات أو المؤسسات أو الهيئات أو الأشخاص عند طلبهم حسب التعليمات النافذة في الجامعة.

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System Lifetime-aware Routing Protocol For Mobile Ad-hoc Networks

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COMMITTEE DECISION

This Thesis (System Lifetime-Aware Routing Protocol For Mobile Ad-hoc Networks) was Successfully Defended and Approved on 3/1/2017

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Dedicated to

For my father, mother, and all my family, for my wife *Saeda Al-Zoughoul*

For their encouragement and understanding during the period of my study and for their sacrifices in past days.

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ABSTRACT

Most mobile ad hoc nodes are battery powered. Hence, power consumption is one of the most challenging issues in routing protocol designed for mobile ad hoc networks (MANETs). Furthermore, replacing or recharging batteries is often impossible in some critical environments. To maximize the lifetime of ad hoc mobile networks, the power consumption rate of nodes must be evenly distributed, and the nodes that have low remaining battery energy must be kept alive as long as possible. These two objectives cannot be satisfied simultaneously by employing routing algorithms that proposed in the related previous works. In this thesis, we proposed a new routing protocol, called the ‘System Lifetime-Aware Routing Protocol’ (SLARP for short) in MANETs, to satisfy these two objectives simultaneously. The performance of the proposed algorithm (SLARP) has been compared to that of the Ad hoc On-Demand Distance Vector Routing (AODV).

When the source node needs to send data packets to a destination node for which it has no known route, it broadcasts a route request towards the destination. When the intermediate node receives the request packet for the first time, it decides whether it can participate in the requested route or not, depending on its residual energy level. If the residual energy in

the intermediate node battery is less than the threshold value, the received route request will be discarded. If the intermediate node has not a valid route to the destination, it will broadcast the processed route request to all its neighbor nodes after recording the congestion and residual energy statuses in the route request. When the destination node receives the route request packets, it selects the best path which contains the intermediate nodes that have the largest residual energy in their batteries that is less than the congestion level, then it sends a route reply packet towards the source node using the inverse of the path that reached.

Extensive simulation experiments have been conducting to examine the performance of the proposed algorithm, and then the performance of the proposed algorithm (SLARP) has been compared to that of the (AODV) algorithm in terms of pause time, a number of sources, bite rate, and simulation time. The simulation results have shown that the performance of the proposed algorithm (SLARP) has been significantly improved in terms of the average end-to-end delay, throughput, overhead, percentage of consumed energy, dead nodes ratio, the average lifetime of dead nodes as compared to the existing algorithm (AODV).

CHAPTER ONE: INTRODUCTION TO MOBILE AD-HOC NETWORK

1-1 Characteristics of Ad hoc Networks

A wireless ad hoc network is a decentralized wireless network, where all nodes cooperatively maintain network connectivity without a central infrastructure. Ad hoc nodes are battery powered. The MANET is a special kind of ad hoc networks, in which nodes can move freely and independently in any direction. Nodes in such dynamic environment need multi-hop paths due to the limitation of the transmission range of the nodes, as well as the rapid changes in the structure of the network. Nodes in MANETs communicate and exchange data using radio signals (30 MHz – 5GHz) [40]. The mobility of nodes in MANETs adds additional power challenges due to the higher messaging transmission rate that is required for optimizing the routes. Each node in ad hoc networks can operate as a host and as a router [33].

1-2 The Applications of Ad hoc Networks

Ad hoc networks have a variety of applications [40], as they can be used anytime, anywhere with limited or no communication infrastructure. Examples of applications that use ad hoc networks include:

- Environmental monitoring: Sensor networks consist of devices that have the capability of sensing, computing, and wireless networking. They are used in various environmental applications, like smoke detectors, monitoring soil, water and air;

- Military scenarios: MANETs support tactical network communications for military vehicles and soldiers in battlefields.
- Rescue operations: Ad hoc networks uses in disaster recovery operations, where they can provide a rapid alternative communication media where a natural disaster occurs.
- Data Networks: A MANET provides support to a permanent network to exchange the data between mobile devices, and it allows sharing the communications media among mobile devices.

1-3 The Current Challenges Facing MANET

Due to its behavior of dynamic network topology, various challenges and limitations face MANETs. Some of these challenges are described below [29, 33, 40]:

- Distributed network: MANET is a decentralized wireless network. That means no centralized administration to manage its operation.
- Dynamic topology: Because the nodes in MANET are mobile. The topology of the network is changing over time. This implies that the routing protocols must be designed to be adaptive for such networks.
- Limited resources: Since the nodes in MANET are battery powered, they have a stern power requirements where the storage capacity and power are severely limited. Thus, the routing protocols should be designed to conserve battery life.

- Addressing scheme: A ubiquitous addressing scheme is required for MANET due to its dynamic topology to avoid any duplicate addresses.
- Security: MANET implies higher security risks, eavesdropping, spoofing and denial-of-service attacks that should be extremely considered in important scenarios such as a battleground.

In this thesis, we focus on the energy efficiency challenge. Where most wireless network devices are portable and battery powered.

1-4 Thesis Target

Usually, mobile nodes mainly depend on battery power for their operations [29]. Thus, the node cannot transmit as well as receive any data when its battery is exhausted. It dies resulting in an impact on network connectivity in MANET, where as soon as one of the intermediate nodes dies, the whole link has to be formed again. This leads to a large amount of end-to-end delay thereby hampering the throughput, the packet delivery ratio, and the overhead of the whole system. The development in battery technology shows that only small improvements in battery capacity can be expected in the near future [29]. Furthermore, increasing the battery size makes the nodes larger and less portable. Recharging or replacing the battery is costly and it may be impossible under some circumstances [40]. Therefore, other steps must be taken to reduce the battery power consumption in the nodes and to reduce the nodes failure, thus enhance the system lifetime. One of the factors that influence the energy consumed by the nodes in ad hoc networks is the routing protocol used.

The main goal of this study is to design and implement a new routing protocol called the System Lifetime-Aware Routing Protocol (*SLARP for short*) that is working to maximize the system lifetime in MANETs, to this end, the power consumption rate of nodes should be eventually distributed over the time. The proposed protocol avoids the routes that contain low power or congested intermediate nodes. Where the congested situation cases excessive consumption of energy in nodes.

Figure 1.1 shows a congested node (D) that is participating in three routes, therefore relatively excessive energy drain will happen in the node (D).

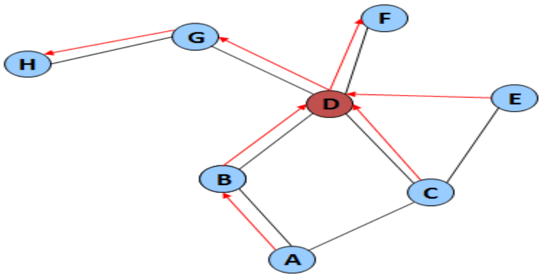

Figure 1.1: A congested node.

1-5 Thesis Outline

This thesis is consisted of seven chapters. Chapter one provides an introduction to ad hoc networks. Chapter two provides a description of the original AODV protocols. Chapter three presents a summary of the related works. Chapter four provides the proposed methodology. Chapter five presents a brief description of the NS-2 simulator environment, scenarios, performance criteria, and the simulation. Chapter six presents the experiments that have been carried out to examine the SLARP and AODV performance, and the results of the experiments have been analyzed in this chapter. Chapter seven provides a conclusion of this thesis and presents some future work ideas.

CHAPTER TWO: AD HOC WIRELESS ROUTING PROTOCOLS

The process of finding paths between message sources and destinations is called routing process. Several routing protocols have been proposed for ad hoc networks [5, 8, 11, 13, 15,20, 23, 25, 26, 30, 38, 39, 40]. These routing protocols use different metrics to discover the optimal route between the participating nodes dynamically. These metrics include the number of hops, throughput, link quality and power frugality. The number of hops is the number of nodes traveled by the packets so far. Throughput is the rate of successful message delivery over a communication channel. Link quality measures the number of packet errors that occur. Power frugality is the consumed energy amount in the nodes.

2-1 Classes of Ad hoc Routing Protocols

Routing protocols in ad hoc networks are classified into three major categories: proactive, reactive and hybrid [8, 28, 33, 40].

Proactive Routing Protocols

Also known as a *table driven* routing protocols, maintain one or more tables containing routing information between each node and every other node in the network. Some of the proactive routing protocols are Destination Sequenced Distance Vector (DSDV) [39], Global State Routing (GSR) [5], Wireless Routing Protocol (WRP) [20], and Optimized Link State Routing (OLSR) [11].

Reactive routing protocols

These protocols are also called *source-initiated* or *on-demand* protocols, the nodes discover routes only when required, *reactive protocols* do not exchange periodic information about the network topology. Some of the reactive routing protocols are Dynamic Source Routing (DSR) [13], Ad Hoc On-demand Distance Vector (AODV) [25], Temporally-Ordered Routing Algorithm (TORA) [23], Associability-Based Routing (ABR) [38] and Cluster Based Routing Protocol (CBRP) [26].

Hybrid routing protocols

Hybrid routing protocols use a combination of proactive and reactive routing methods, which is better than using each method in isolation. Examples of hybrid routing protocols are Zone Routing Protocol (ZRP) [8] and Hazy-Sighted Link State routing protocol (HSLS) [38].

2-2 Ad-hoc On-demand Distance Vector (AODV) routing protocol

To identify the shortest fresh path to carry the data between the source and the destination AODV uses a reactive approach called a route discovery process. To compute the shortest fresh routes and it ensures that these routes do not contain loops it uses the destination sequence numbers. The mechanisms of the phases of AODV described below.

Route Discovery

When a node need to send data to another node that it does not has it address, it will be broadcasting a route request (RREQ) packets to its neighbors including some such as destination identifier (DId), destination sequence number (DSeq), source identifier (SId), source sequence number (SSeq), broadcast identifier (BId), and time to live (TTL) fields. Each neighbor that has been received the broadcasted RREQ uses the Sid, Bid, and SSeq fields to determine if the received RREQ has been previously received or not, to avoid the duplication and prevent the routing loops. Then intermediate node will check its cache for an available valid route to the destination, if yes it will send a Route Reply (RREP) packet to SId, otherwise it will broadcast the RREQ packet. The intermediate node sets up a reverse route entry to the source node to send a route reply packet (RREP). The reverse route entry consists of a source identifier the address of the node from which RREQ was received, number of hops to the source node, and lifetime field [25].

Figure 2.1 provides an example of route discovery process in AODV. Where node A initiates a route discovery process, it will insert the SId, SSeq, BId, Did, DSeq and TTL fields in a RREQ packet then broadcast the RREQ to its neighboring nodes (B, C, and D).

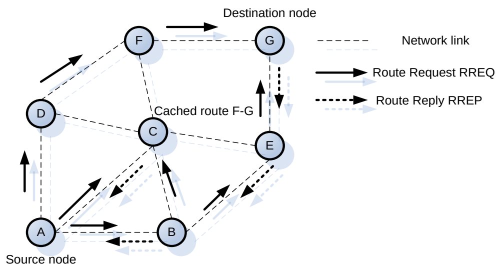

Figure 2.1: Route discovery in AODV[35]

Nodes B, C, and D, nodes search their route caches for an existing valid route when the RREQ packet reaches them. If there is no a valid route in any intermediate node, it will forward the RREQ to its neighbors. In Figure 2.1, node C has a valid route to G in its cache and its DSeq is greater than the DSeq in the RREQ. Then it will send a RREP back to the source node A.

Route Maintenance

A node determines connectivity information by listening to hello messages from its neighbors [25]. A node broadcasts a RERR packet to notify the source and the end nodes it finds out a link break [25].

Figure 2.2 illustrates this process where the link between nodes C and F breaks on the active route A-C-F-G. When both nodes C and F detect this broken link, they will broadcast a RERR packets to notify the source and the destination nodes about this broken link. Thus, the source will start a new route discovery process to find a new route to the destination.

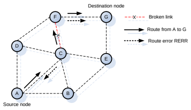

Figure 2.2: Route Maintenance in AODV [35]

CHAPTER THREE: RELATED WORKS

As a MANET lacks a centralized infrastructure and mobile nodes in MANET are battery powered, many research efforts have been devoted to developing power-aware routing protocols. A localized, a fully distributed power aware routing algorithm is proposed in [34]; it assumes that each node has information about the locations of its neighbor nodes as well as the destination. Each node computes the costs of links to its neighbor nodes as well as to the destination. Based on this, the source selects the next hop through which the overall transmission power to the destination is minimized. The disadvantage of this protocol is that in some cases the direct transmission consumes more power as compared to the indirect transmission through intermediate nodes [40]. Moreover, it does not take into account the congestion that may be occurring in intermediate nodes, which can cause a drain of the energy in these nodes.

The protocol in [24] provides an enhancement to the AODV protocol, where it proposes a modification to control packets that contain power control information during route discovery in AODV. The main objective of this protocol is to reduce power consumption to a minimum power level in MANETs without disruption of network connectivity. It makes use of several power levels during route discovery; initially, nodes attempt to find a route with low power levels. If it does not succeed, then the power level is increased until it can find a route.

In [37], the proposed protocol uses the idea of a threshold to maximize the lifetime of each node and to use the battery fairly. The protocol selects the shortest path if all intermediate nodes of a route have larger remaining battery energy than the threshold, which called min-power route. If all intermediate nodes in the possible routes have a lower battery capacity than the threshold, then the protocol will select a route that consists of nodes that have maximum remaining battery energy, this route called the max-min route. When the remaining battery energy for some intermediate nodes goes below a predefined threshold, routes going through these nodes will be avoided. The disadvantage of this protocol is that, when the threshold value is larger than the transmission power value, some nodes that have a level of remaining battery energy less than threshold value will be avoided. Therefore, congestion and drop in energy will happen on other nodes.

In [18], a protocol based on AODV is proposed. It is supposed that a virtually unlimited power supplies are equipped with some nodes, while the other nodes have a limited power supply like a battery. It is proposed to create infrastructure ad hoc networks by deploying a number of immobile nodes that have a constant power supply, act only as routers. These nodes are called pseudo base-stations (PBSs). Thus, allowing the mobile nodes to save power because they are not acting as routers. This protocol tries to select routes that go through PBSs instead of mobile nodes to reduce the amount of power consumed by these mobile nodes. Furthermore, it allows nodes to enter a power saving mode, subsequently reducing the power consumption compared to AODV [17, 18]. Nevertheless, under some circumstances, it is impossible to create such an infrastructure ad hoc network, such as in military conflicts and natural disaster circumstances.

In [19], an extension to the AODV protocol is proposed. It uses a new routing cost model to discourage the use of nodes running low on battery power. This routing protocol saves energy by turning off radios when the nodes are not in use. The energy-aware protocol works only in the routing layer. Although it was implemented in the AODV protocol, the technique can be used with any on-demand routing protocol. The disadvantage of this protocol is that in some cases, like environmental monitoring, a sensor needs to be sensing, computing and sending all the time.

In [3], an extension to the DSR protocol is proposed. It provides a new feature for energy limited nodes, by finding the lowest energy routes rather than minimum hop routes during route discovery. Depending on the remaining battery energy, a node determines whether to forward the route request message or not. When the remaining battery energy is higher than a threshold value, the node will forward the route request; otherwise, it will drop the message and refuses to participate in routing. The disadvantage of this protocol is that it may cause energy drain on the farthest nodes that have large remaining battery energy in the case that some close nodes with lower battery capacity are avoided.

In [27], an extension to the DSR protocol is proposed, which codenamed, Power-aware routing (PAR). It provides an improvement in the availability of ad hoc networks by considering three parameters at the time route selection: Accumulated energy of a path, Status of battery lifetime and Type of data to be transferred. PAR always selects less congested and more stable routes for data delivery and can provide different routes for a different type of data transfer and ultimately increases the network lifetime. PAR can somewhat incur increased latency (i.e. a time interval that taken by the packet to travel from source to destination) during data transfer, it discovers routed that can last for a long time and encounter significant power saving.

In [30], an extension to DSR is proposed. It modifies the route discovery procedure for balanced energy consumption. This protocol concurrently optimizes the trade-off between balanced energy consumption and minimum routing delay and avoids the blocking and route cache problems. The disadvantage of this protocol is that it causes high route request overhead because route requests may be repeated due to dropping the requests by intermediate nodes.

In [4], a mechanism that aims to reduce power consumption of the nodes by operating between the routing layer and the media access control (MAC) layer is proposed, codenamed SPAN. It coordinates the “stay-awake and sleep” cycle of the nodes and performs a multi-hop packet routing within the ad hoc networks, while other nodes remain in power saving mode and occasionally check if they should remain awaken and become a coordinator. The adaptive election of protocol coordinators is done by using a random back-off delay in each node for indicating whether to become a coordinator or not. The back-off delay for a node is a function of its neighbor numbers and residual energy in these nodes. This technique provides good energy saving. The disadvantage of this protocol is that the amount of power saving increases slightly as density decreases.

In [6], an extension to DSR is proposed codenamed MEA-DSR protocol, where a multi-path energy-aware on-demand source routing protocol is proposed. It exploits route diversity and information about batteries’ energy levels, for balancing energy consumption between mobile nodes. MEA-DSR limits the number of routes that a destination node provides to a source node to two. It shows that the performance advantage of using more than one or two alternate routes is minimal. The primary route in MEA-DSR is chosen by two factors: the first is the residual energy of nodes belonging to the route. The second is the total transmitting power that requires sending data on this route.

CHAPTER FOUR: THE PROPOSED PROTOCOL

The objective of the new routing protocol SLARP is to increase the system lifetime by finding a route with intermediate nodes that are less busy and have largest residual energy. We used the ideas of a threshold, residual energy and congestion factor simultaneously to find the desired route, thus ensuring avoid the congestion that may get on some intermediate nodes, which it leads to energy depletion in these nodes.

SLARP selects a less busy shortest route (minimal number of hops) through the intermediate nodes that have a largest residual energy that is greater than the threshold value. Threshold value represents the critical value of the remaining portion of battery energy in nodes. It may need to be periodically tuned to achieve the maximum system lifetime.

When the residual energy of some intermediate nodes goes below a predefined threshold value, routes going through these nodes will be avoided, even if this leads to selecting a more congested route. By doing this, nodes with low residual energy will give up playing the role of the router. The lifetime of these nodes will be extended; when these nodes give up their roles as routers, thereby increasing the overall system lifetime.

When SLARP fails to find the desired route for more than two attempts it will abandon the threshold condition and works as in the original AODV. This is because after fails the third attempt to find the desired route the "DROP_RTR_NO_ROUTE" status will be declared in the network to inform the source that is currently no route to the desired destination as in the original AODV.

SLARP designed to be reactive (on-demand) and vector protocol (hop-by-hop) due to the dynamic behavior of MANETs like the original AODV. It discovers routes from source to destination and selects the best route according to the values of packet queue length and residual energy.

The destination will calculate the power-congestion factor (PCF), which is the main metric of selecting the route in SLARP. PCF is calculated using a factor (α) as shown in Equation 1.

$$\mathbf{PCF} = \boldsymbol{\alpha}\left(\frac{\mathbf{MinRBE}}{\mathbf{IBC}}\right) + (\mathbf{1} - \boldsymbol{\alpha})\left(\square - \frac{\mathbf{MaxPQL}}{\mathbf{PQL}}\right) \qquad \text{...} (1)$$

The IBC is the initial battery energy in nodes; we assume that all nodes have the same initial battery energy. The PQL is the Length of the packet queue in nodes; we assume that all nodes have the same PQL. The value of the weight factor (α): is between 0 and 1, and MinRBE and MaxPQL are defined below.

Nodes cached valid routes as long as these routes are used. Nodes use the routing control packets to find and fix the routes. In the proposed algorithm, there are three types of control packets: RREQ, RREP, and RERR packets, as in [13, 15, 25, 39].

An RREQ packet contains the following fields:

- Source Identification (SID): represents the address of the source node, which needs to discover the route.
- Destination Identification (DID): represents the address of the node to which a route is to be found.
- Sequence Number (SEQ): a unique number that is assigned to each new source node RREQ; it is used to detect duplicate RREQ packets.
- Minimum Residual Battery Energy (MinRBE): represents the minimum remaining battery energy among all the intermediate nodes in the route visited by the RREQ so far.
- Maximum Packet Queue Length (MaxPQL): represents the maximum packet queue length among all the intermediate nodes in the route visited by the RREQ so far.
- Number of Hops (HOP): represents the number of nodes traveled by the RREQ so far.
- Time-To-Live (TTL): represents the maximum number of nodes that the RREQ can reach before it is discarded. This value is used to avoid route loops.

An RREP packet contains the following main fields:

- Source Identification (SID): is the DID in the RREQ.
- Destination Identification (DID): is the SID in the RREQ.

- Sequence Number (SEQ): a unique number that is assigned for each RREP from the responding destination node; it is used to detect duplicate RREP packets.
- Minimum Residual Battery Energy (MinRBE): represents the minimum remaining battery energy among all the intermediate nodes in the discovered route.
- Maximum Packet Queue Length (MaxPQL): represents maximum packet queue length among all the intermediate nodes in the discovered route.
- Number of Hops (HOP): represents the number of nodes traveled by the RREP so far.
- Time-To-Live (TTL): maximum number of nodes that the RREP can travel before it is expired.

An RERR packet contains the following main fields:

- Source Identification (SID): represents the address of the node that initiated the RERR.
- Destination Identification (DID): represents the address of the source node that is attempting to use the failing link.
- Sequence Number (SEQ): a unique number that is assigned to each RERR by the node that detected the route error; it is used to detect duplicate RERR packets.

The proposed algorithm consists of the following main phases:

4-1 Route Discovery Phase

In the route discovery stage, the source node will initiate a route discovery process by broadcasting an RREQ packet to all neighbor nodes.

When an intermediate node receives an RREQ, it has to do the following:

- If the SEQ number of the received RREQ has been previously received, the received RREQ will be discarded.
- Else {
    - If residual energy in its battery is less than the threshold value, the received RREQ will be discarded.
    - Else {
        - If it has a valid route to the destination, it will send a new unicast RREP packet to the sender.
        - Else {
            - If the received RREQ has a MaxPQL value that is smaller than the node's PQL value, then the MaxPQL field of the received RREQ will be replaced by the node's PQL value.
            - If the received RREQ has a MinRBE value that is larger than the node's RBE value, then the MinRBE

```
            field of the received RREQ will be replaced by the
            node's RBE value.
          • Then it will broadcast the processed RREQ to all its
            neighbor nodes.
            }
        }
    }
```

When the destination node receives an RREQ, it will do the following:

- If the SEQ number of the received RREQ has not been previously received, then it will send a unicast RREP packet to the sender using the reverse path.
- If the SEQ number of the received RREQ has been previously received, then it will calculate the PCF value of the new RREQ, and do the following:
  - A. If the new PCF value is greater than the previous value, then the destination will send a new unicast RREP packet to the sender.
  - B. Else, the received RREQ will be discarded.

When the intermediate nodes receive a RREP, it will update its routing cache.

When the source node receives a RREP, it will do the following:

- If the SEQ number of the RREP has not been previously received, then it will add this route to its routing cache and begin transmitting the data packets to the destination using this route.
- If the SEQ number of the RREP has been previously received, then it will update its routing cache to use the new route.

4-2 Route Maintenance Phase

Due to the dynamic behavior of the MANETs, some intermediate nodes of an active route may go out of the radio transition range causing a link failure. The route maintenance process will be done as in AODV protocol [25].

CHAPTER FIVE: EXPERIMENTAL SETUP

5-1 Simulation Tool

Many network simulators are available. Some of the more popular ones are network simulator (NS), GloMoSim, CSIM, and OPNET [7]. Our algorithm has been implemented and experimented with the NS version 2.35. NS-2 network simulator plays an important role in the research field of MANET for the following features [7]:

1. Uses by a large number of institutes and researchers for a prototype of network simulation in research studies.
2. Comes with a rich suite of algorithms and models that is easy to modify.
3. Supports a large number of built-in industry standard network protocols applications.
4. Provides rich data analysis features.
5. It is open source software.
6. Compatible with the different operating systems, such as Linux and Windows.

5-2 General Structure and Architecture of NS-2

NS-2 mixes between two programming languages C++ and object oriented extension Tool Command Language (OTCL) [21], this combination leads to a sort of compromise between performance and ease of use. By writing a TCL script, the general user can design and run the simulations by initiating an event scheduler and setting up the network topology using the simulator objects in the OTCL library. The network components objects and event schedulers are implemented and compiled using the C++. These objects are available to OTCL through an OTCL linkage that creates a matching between the OTCL objects and the C++ objects [7, 9, 21].

The simulation results from running the TCL script in NS-2 include one or more output files with text-based format and an input to a graphical simulation display tool called Network Animator (NAM) [7]. The text based files record the activities taking place in the network, which can be analyzed by other tools such as ‘Perl’ or ‘Gwak’ so as to evaluate the results. The NAM file is an animation file that has been used for viewing network simulation traces and real world packet traces.

5-3 Wireless Node and Network Topology Configuration in NS-2

The **NS-2** simulator has many parameters. These parameters are used to set the nodes configuration and to specify the other parameters to be used to determine the network topology and environment. The user needs to write a TCL file in which all of these needed configurations must be set. Node configuration in NS-2 is a special task in which a number of nodes can be configured for a set of parameters. The following table describes the node configuration parameters as defined in the *ns-lib.tcl* file.

Table 5.1: Node configuration parameters

Parameter	**Available Values**	**Remarks**
Address Type	flat, hierarchical	

MPLS	ON,OFF	Multiprotocol Label Switching
Wired Routing	ON, OFF	
llType	LL, LL/Sat	Link layer Simulation of data link layer protocol including packet fragmentation and assembling, and reliable link protocol. ARP Connect to LL resolves all IP to MAC address.
macType	Mac/802_11, Mac/Csma/Ca, Mac/Sat, Mac/Sat/UnslottedAloha, Mac/Tdma	Medium Access Control Can choose IEEE 802.11 protocol or TDMA as the MAC layer mechanism.
ifqType	Queue/DropTail, Queue/DropTail/PriQueue	Interface Queue type The class PriQueue is implemented. It provides priority to routing protocol packets by inserting them at the head of the queue.
phyType	Phy/wirelessPhy, Phy/Sat	Physical Layer Type
adhocRouting	DIFFUSION/RATE, DIFFUSION/PROB, DSDV, DSR,FLOODING, OMNIMCAST, AODV, TORA, PUMA	ad-hoc routing protocol
propType	Propagation/TwoRayGround, Propagation/Shadowing	Propagation Type, Radio propagation model it used Free-space attenuation at near distance and two-ray ground at a far distance.
antType	Antenna/OmniAntenna,	Antenna type
Channel	Channel/WirelessChannel, Channel/Sat	Channel to be used
mobileIP	ON,OFF	to set the IP for Mobile or not
energyModel	EnergyModel	energy model to be enabled or not
initialEnergy	<joule>	in terms of joules (Ex: 3.24)
txPower	< Watts >	Power in terms of Watts (0.32)
rxPower	< Watts >	Power in terms of Watts (0.1)
idlePower	< Watts >	Power in terms of Watts (0.02)
agentTrace	ON, OFF	Tracing to be on or off
routerTrace	ON, OFF	Tracing to be on or off
macTrace	ON, OFF	Tracing to be on or off
movementTrace	ON, OFF	Tracing to be on or off

The network topology and environment parameters include:

1. Simulation Time: this parameter specifies the total simulation time in seconds.

2. Seeds: this parameter specifies different seed values for random number generator.
3. Terrain-Dimensions**:** this parameter specifies the dimension of the simulated area.
4. Number-of-Nodes**:** this parameter specifies the number of nodes in the simulation area.
5. Mobility Style**:** this parameter specifies the style of node mobility. **NS-2** supports different mobility styles. If mobility is set to the *random-drunken* model, and the node's current position is (x, y), then the node can move randomly to (x-1, y), (x+1, y), (x, y-1), and (x, y+1). However, the most widely used mobility style is *random-waypoint* style [7]**.** In this type of mobility, a node randomly chooses a destination in the terrain area and moves in the direction of this position with a speed uniformly chosen between the *Min-Speed* and *Max-Speed.* When the node reaches its destination, it stays there for a period of time specified by the parameter *Pause-Time.* Then, it selects another destination and moves towards it.

Creating Random Traffic Pattern for Wireless Scenarios in NS-2

To achieve a fair comparison between different protocols, we need to evaluate each of them in the same simulation environments such as nodes configuration, network topology, environment parameters, traffic connections and nodes-movement.

The traffic connection file contains a number of TCP or CBR traffics connections that were randomly generated using a *traffic scenario generator script* to setup connections between wireless mobile nodes. This *traffic generator script* is available under *~ns/indep-utils/cmu-scen-gen* and it is called *cbrgen.tcl*. To create a traffic connection file, we need to define the type of traffic connection Constant_Bit_Rate (CBR), the number of nodes and maximum number of connections to be set up between them, a random seed and in case of CBR connections, a rate whose inverse value is used to compute the interval time between the CBR packets. So the command line looks like the following:

```
ns cbrgen.tcl [-type cbr|tcp] [-nn nodes] [-seed seed] [-mc connections] [-rate rate]
```

We have used the CBR as a model of sending data packets from sources to destinations. For example, to create a CBR connection file between 12 nodes, having a maximum of 7 connections, with a seed value of 1.0 and a rate of 4.0 for example. The command used is:

```
ns cbrgen.tcl -type cbr -nn 10 -seed 1.0 -mc 7 -rate 4.0 > cbr-12-test
```

The simulator uses an appropriate model for each layer. We have used the CBR model for the application layer, the User_Datagram_Protocol (UDP) model for the transport layer, the IEEE 802.11 model for the MAC layer and we have used the AODV and SLARP for the network layer, as can be seen in Table 5.2.

Table 5.2: Models used for different layers

Layer	**Model**
Application	CBR
Transport	UDP
Network	AODV / SLARP
Mac Layer	802.11

Creating Nodes Movements for Wireless Scenarios in NS-2

As we mentioned earlier, to achieve a fair comparison between different protocols, we need to evaluate each of them in the same simulation conditions. NS-2 provides a generator to create a nodes-movements file called *setdest*, which is available under *~ns/indep-utils/cmu-scen-gen/setdest* directory.

We need to define the number of nodes in the environment, the pause time, the maximum speed of mobility, the simulation time, the Maximum length of the area, Maximum width of the area and the movement file in which all movements will be stored. So to create a nodes-movements file we need to run *./setdest* generator with arguments as shown below:

```
./setdest [-n num_of_nodes] [-p pausetime] [-s maxspeed] [-t simtime] [-x maxx] [-y maxy] > [movement-file]
```

For example, to create a node-movement scenario consisting of 20 nodes moving with the maximum speed of 13.0m/s with an average pause between movements being 3s. We want the simulation to stop after 400s and the topology boundary is defined as 500 X 500. So the command line will look like:

```
./setdest -n 20 -p 3.0 -M 13.0 -t 400 -x 500 -y 500 > scen-20-test
```

We have used the following parameters, as shown in Table 5.3, to generate different movement scenarios, this environment is commonly used [30].

Table 5.3: The parameters used in generation movement scenarios.

Parameter	**Value**	**Interpretation**
Number of Nodes	50	Total number of nodes in the scenario
Pause Time	0, 100, 200, 300	Duration when a node stays still after it arrives a location. If this value is set to 0, it means that the node won't stop when it arrives a location and keep on moving.
Maximum Speed	10	Maximum moving speed of nodes. Nodes will move at a

		random speed choosing from the range [0, maxspeed].
Simulation Time	700	Simulation time.
X-Dimension	1000	The maximum length of the area.
Y-Dimension	1000	Maximum width of the area.

5-4 Performance Criteria

Many performance criteria are used to evaluate the performance of ad hoc networking protocols. The following is a brief description of such performance criteria :

Dead Nodes Ratio

Dead nodes ratio is the ratio of the number of nodes that died out at a time of simulation due to the consumption of the whole energy supplied to them to the total number of nodes in the network [1, 14, 31, 35]. For instance, if by a time of simulation, the number of nodes that consumed the whole energy in its battery equal to 20 nodes, and the total number of nodes in the network is 50, then the dead nodes ratio is 40%. This performance criteria gives an estimate of how the power efficiency of a routing protocol is, where a protocol with the higher dead nodes ratio is consequently the lower power efficiency protocol.

Average Lifetime of Dead Nodes:

It is the average lifetime of the dead nodes in the network at a time of simulation. For instance, if by a time of simulation, the number of nodes that consumed the whole energy in its battery is four nodes where the failure of the first one happened at 300 sec of simulation time, the second at 330 sec, the third at 350 sec, and the fourth at 360. Then the average lifetime of the dead nodes in the network is 335 sec. This performance criteria gives an estimate of how the power efficiency of a routing protocol is, where a protocol with the higher average lifetime of the dead nodes is consequently the higher power efficiency protocol.

Percentage of Consumed Energy (PCE):

It is the percentage of the consumed energy in the network; it can be calculated by the following equation:

Where,

N: The number of nodes used in the network.

RE: Residual energy in the node.

IE: The initial energy used for the node in the network.

The initial energy was set to 100 *Joules* for each node in all simulation runs in this study; to maintain the connectivity in the network for the entire duration of the simulation time.

This performance criteria gives an estimate of how the power efficiency of a routing protocol is, where a protocol with the higher PCE is consequently the lower power efficiency protocol.

Packet Delivery Ratio:

The delivery ratio is the ratio between the total number of received data packets to the total number of sent data packets [2, 12, 16, 22]. For instance, if by the end of the simulation, the destinations have successfully received 900 data packets from 1000 data packets that were sent by the network layer, then the delivery ratio is 90%. This performance criteria gives an estimate of how efficient a routing protocol is. A protocol with the higher packet delivery ratio is consequently the higher efficiency protocol.

Average End-to-End Delay:

It is the average delay of all data packets that were sent from sources to destinations. It includes all delays that possibly are caused during buffering in route discovery, queuing delay at the interface, retransmission delays at the MAC, propagation and transfer times [2, 12, 16, 22]. A protocol with the higher average end-to-end delay is consequently the lower efficiency protocol.

Throughput:

It is defined by the amount of received data by the destination nodes in a period of time [2, 12, 16, 22]. A protocol with the higher throughput is consequently the higher efficiency protocol.

The Overhead:

The overhead is the total number of control packets sent divided by the total number of data packets received. For example, if we send 1000 control packets for 500 received data packets, then the overhead is 2, which means that for every 1 data packet to be delivered we need 2 control packets [2, 12, 16, 22]. This performance criteria gives an estimate of how the efficient of routing protocol is. A protocol with the higher overhead of routing packets is consequently the lower efficiency protocol.

5-5 Scenario Setup

In this thesis, we set up a network with 50 mobile nodes placed randomly within 1000*1000 meter area. Each node has a radio propagation range of 250 meters and the channel capacity is 2 Mb/s. Each run lasted for 700 seconds of simulation time. A traffic generator was used to simulate CBR sources. The size of the data payload was 512 bytes. We have used random waypoint model as the mobility model. The minimum and maximum speeds were set to zero and 10 m/s, respectively. To comprehensively measure the performance of our algorithms, we have used the pause times 0, 100, 200, 300 each experiment. Also, we varied the transmission rate for 1, 2, 4 and 6 packets per second, repeated for 5, 10, and 15 sources; resulting in forty eight different experiments as a whole. Other simulation parameters are summarized in table 5.4.

Table 5.4: Simulation Parameters

Parameters	**Value**
Simulator	NS-2(Version 2.35)
Maximum Packet in Queue	50
Area (m*m)	1000*1000
Number of mobile nodes	50

simulation time	700
Source Type	UDP
Routing Protocols	AODV, SLARP
MAC Type	IEEE 802.11
Initial Energy	100

CHAPTER SIX: SIMULATION RESULTS ANALYSIS

In this chapter, the simulation results for two routing protocols (AODV and SLARP) have been collected. A scenario was set up for data collection. This scenario was run many times with four different values of the mobility pause time, three different numbers of sources, four different values of packet transmission rate as previously reported in chapter 5. We have implemented the algorithms in the NS simulator version 2.35 and compared the performance of the SLARP algorithm to that of the AODV algorithm (developed by the CMU/MONARCH group, which was optimized and tuned by Samir Das and Mahesh Marina, University of Cincinnati) [10].

The data has been collected according to seven performance criteria – the Packet Delivery Ratio, Average End-to-End Delay, Throughput, Overhead, Percentage of Consumed Energy, Dead Nodes Ratio and Average Lifetime of Dead Nodes. According to the equation (1) shown in chapter 4; we used different values for weight factor (α) and threshold (k), to determine the appropriate values for α and k in which the new protocol (SLARP) achieves the best results.

Nodes moving direction, nodes speed, congestion level in the intermediate nodes these factors and other affect the actual values of the performance criteria in each scenario. To obtain representative values for the performance criteria of the SLARP and AODV protocols, simulation results for four values of mobility pause times are averaged over ten simulation runs for each scenario so that the confidence level is 95% that relative errors are below 5% of the means, as shown in appendix A.

In the following sections, we analyze each performance criteria for the two protocols (SLARP and AODV) with $\alpha = 0.5$ and $k = 0.5$. The simulation results for the other values of α and k are included in appendix B. Table 6.1, illustrates the values of α and k.

Table 6.1: The values of α and k.

Weight Factor (α)	**Threshold (k)**
0.25	0.25
0.25	0.50
0.25	0.75
0.50	0.25
0.50	0.50
0.50	0.75
0.75	0.25
0.75	0.50
0.75	0.75

6-1 Dead Nodes Ratio (DNR)

The node consumes energy in sending, receiving or forwarding the packets and in its mobility. By increasing the simulation time values, the number of sources and the transmission rate, nodes need to consume more energy to service the required connections and probably they will lose the whole of their batteries power. SLARP maintains nodes energy and system lifetime as much as possible by distributing the data traffic loads according to the amount of residual energy and the congestion level of the intermediate nodes to avoid the congestion as much as possible, which causes depletion in the congested nodes energy. Congestion infection transmits from node to another after it has been drained node power in serving the required connection.

Moreover, an amount of energy will waste again to find a new route in the event of dying an intermediate node. This justifies the superiority of SLARP over AODV in terms of dead node ratio for all simulation time values that have an dead node. This is shown in the figures 6.1~6.8 for all number of sources and transmission rates considered in this research work.

In figure 6.8, for example, SLARP outperforms AODV by 90.87, 52.19, 37.48, 33.40, and 32.66 percent when the simulation time values are 300, 400, 500, 600, and 700 secs, respectively.

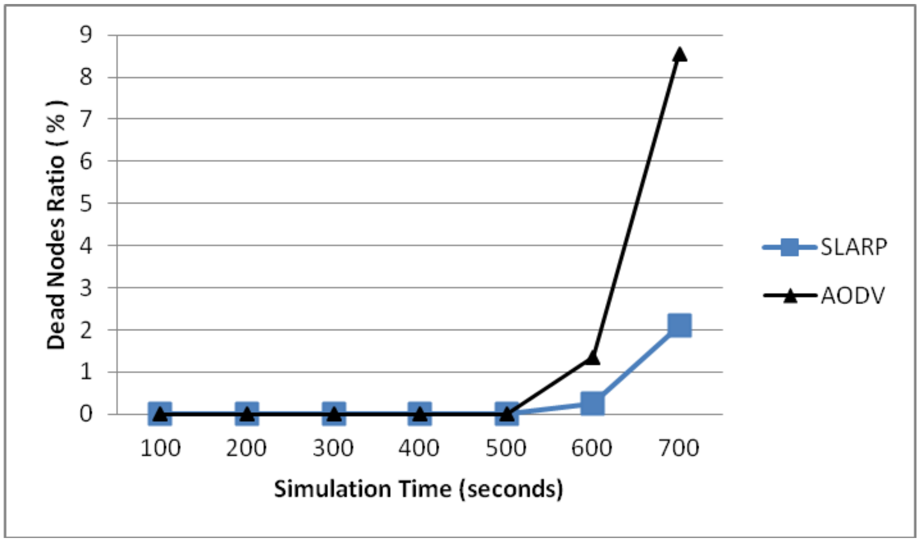

Figure 6.1: The dead nodes ratio of five sources, each sends four packets per second.

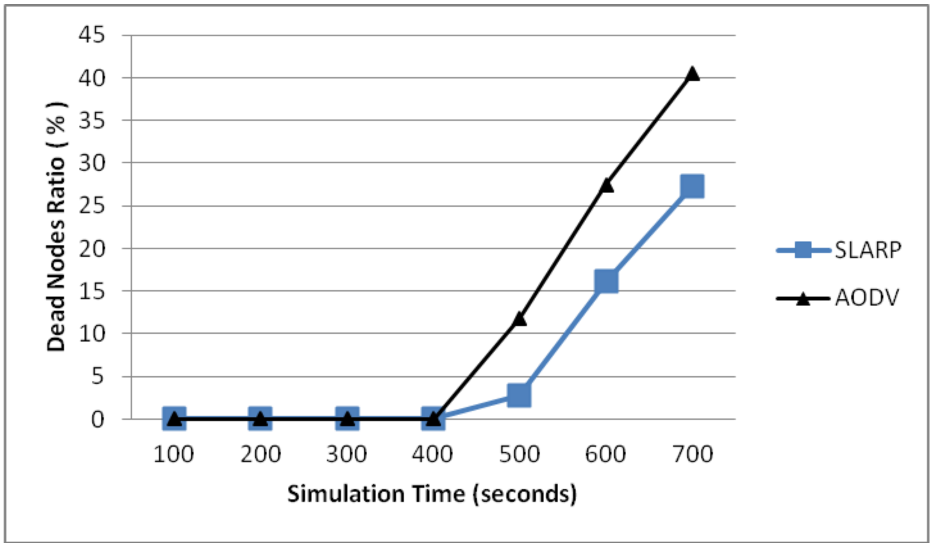

Figure 6.2: The dead nodes ratio of five sources, each sends six packets per second.

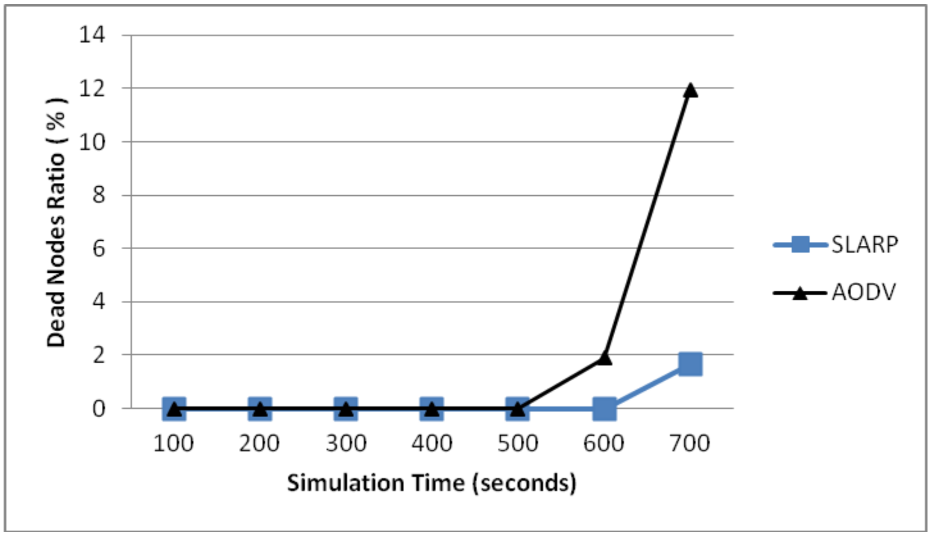

Figure 6.3: The dead nodes ratio of ten sources, each sends two packets per second.

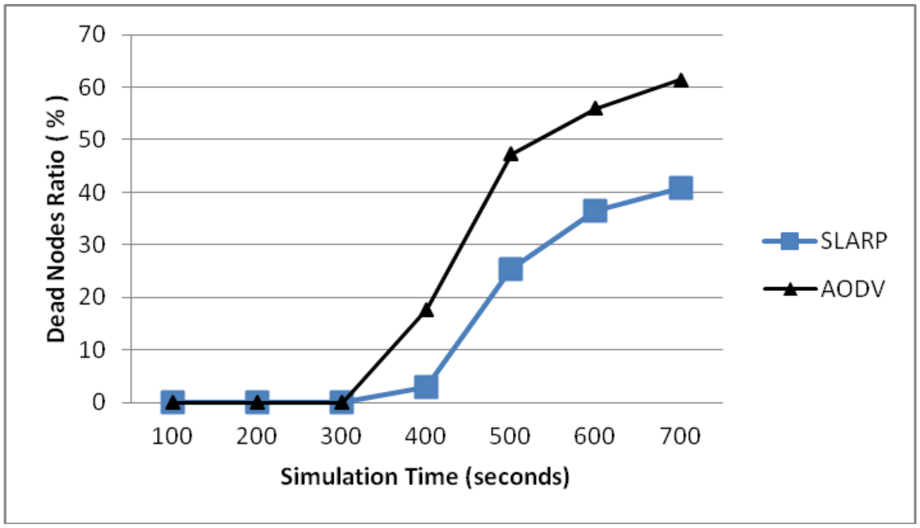

Figure 6.4: The dead nodes ratio of ten sources, each sends four packets per second.

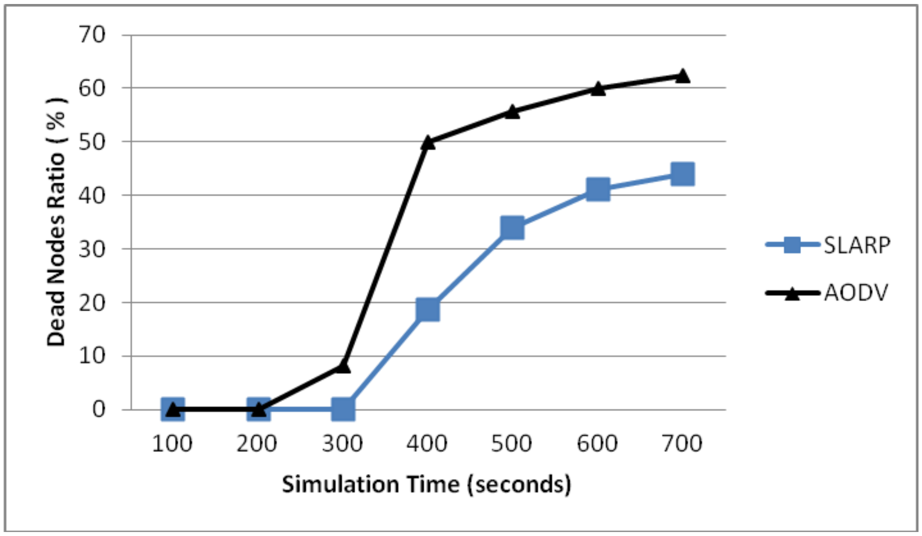

Figure 6.5: The dead nodes ratio of ten sources, each sends six packets per second.

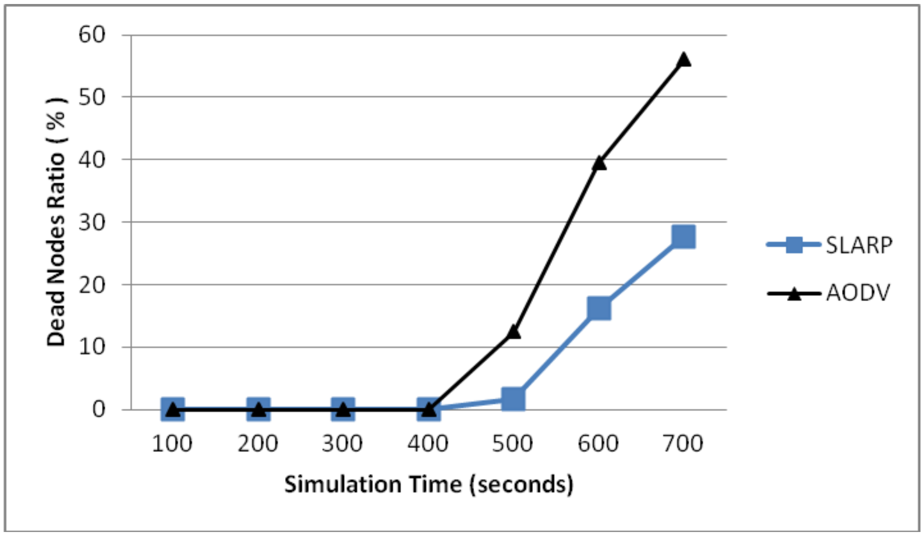

Figure 6.6: The dead nodes ratio of fifteen sources, each sends two packets per second.

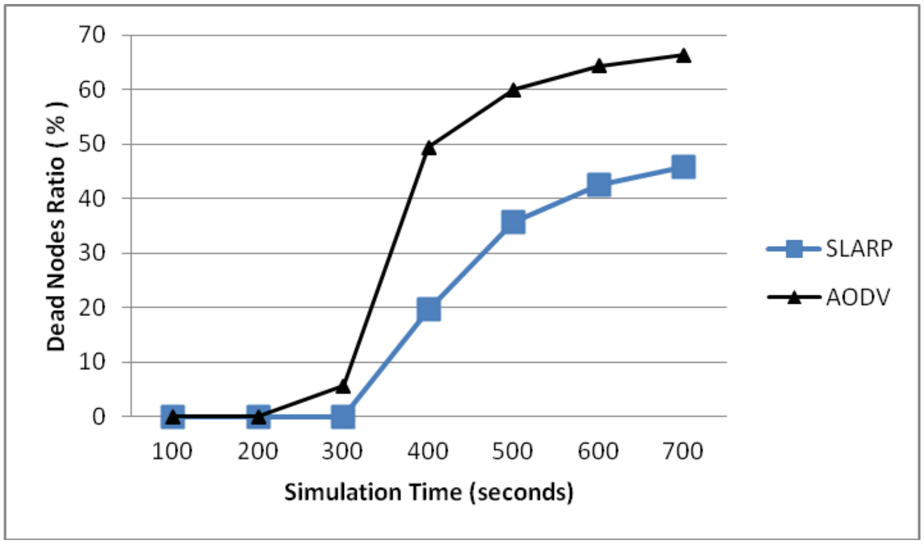

Figure 6.7: The dead nodes ratio of fifteen sources, each sends four packets per second.

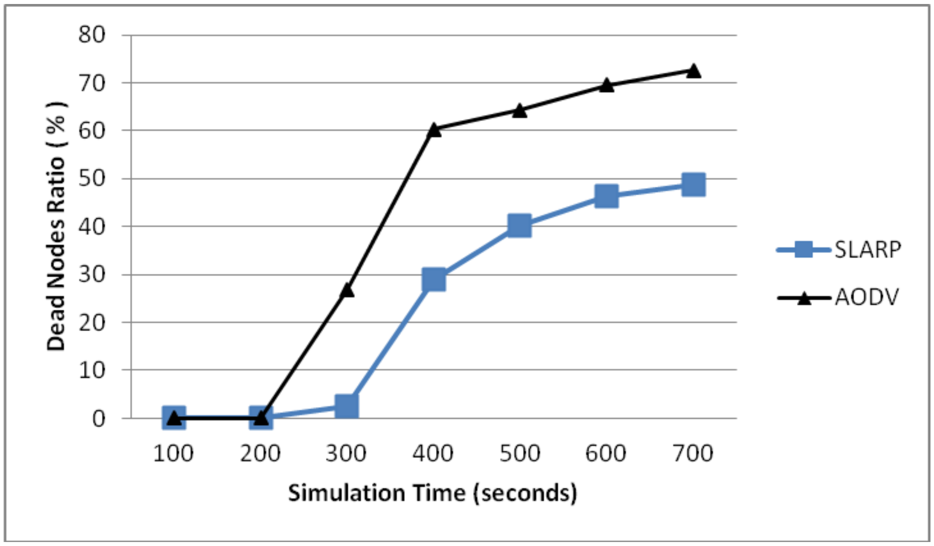

Figure 6.8: The dead nodes ratio of fifteen sources, each sends six packets per second.

In the light-load data traffic networks, no dead node in such networks for SLARP and AODV. This is shown in figures 6.9~ 6.12 for the number of sources and transmission rates considered.

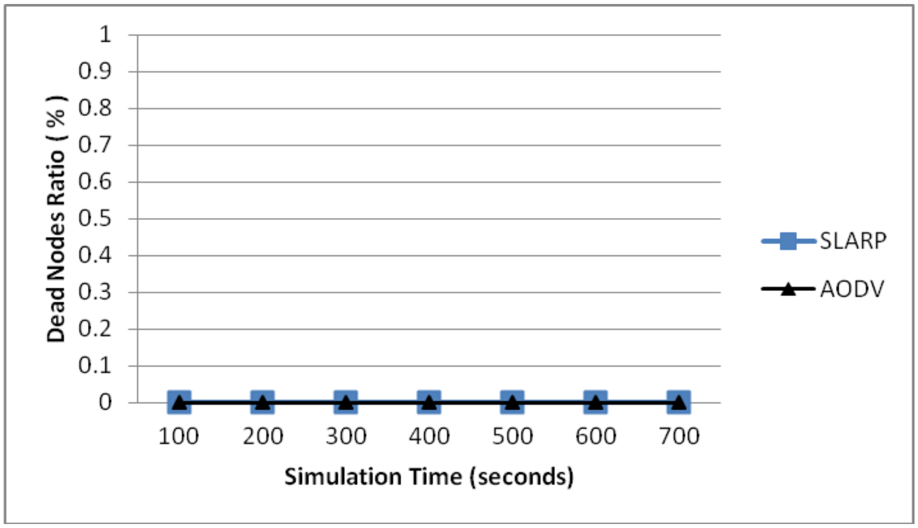

Figure 6.9: The dead nodes ratio of five sources, each sends one packet per second.

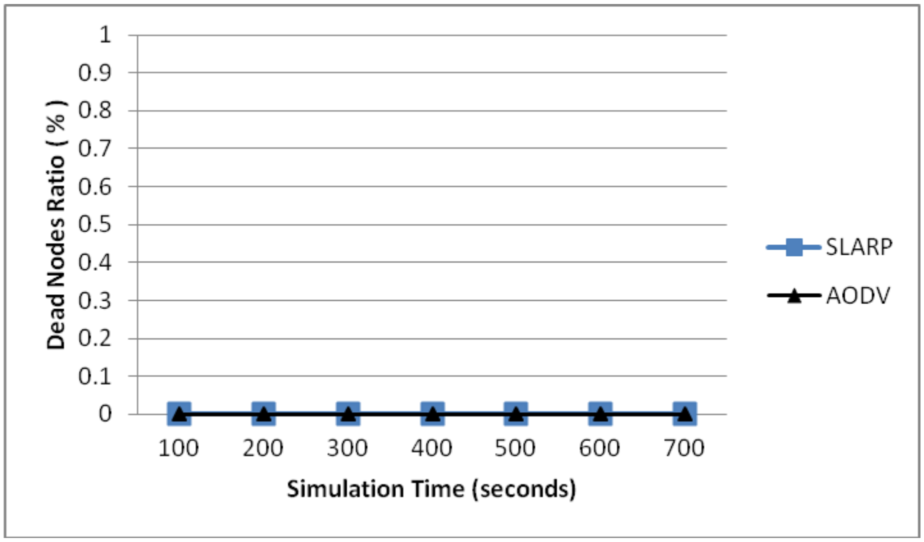

Figure 6.10: The dead nodes ratio of five sources, each sends two packets per second.

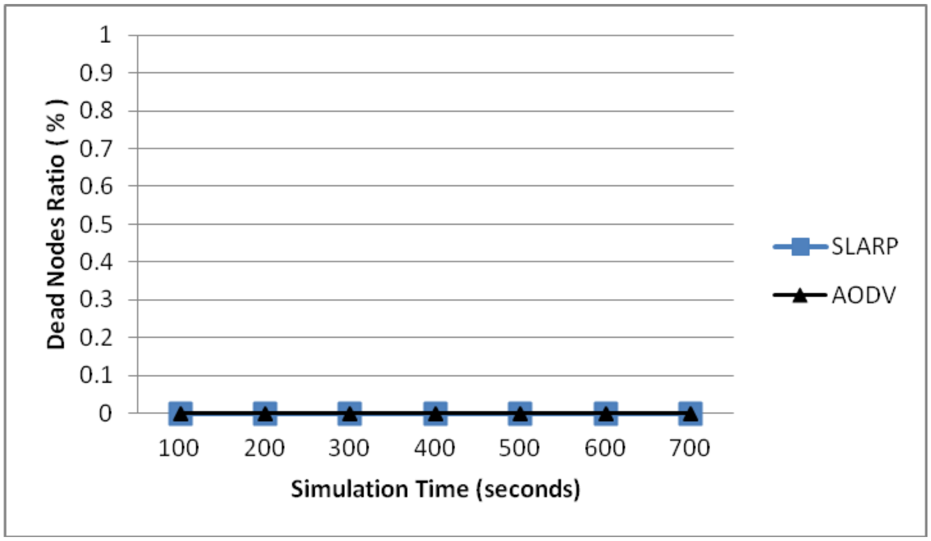

Figure 6.11: The dead nodes ratio of ten sources, each sends one packet per second.

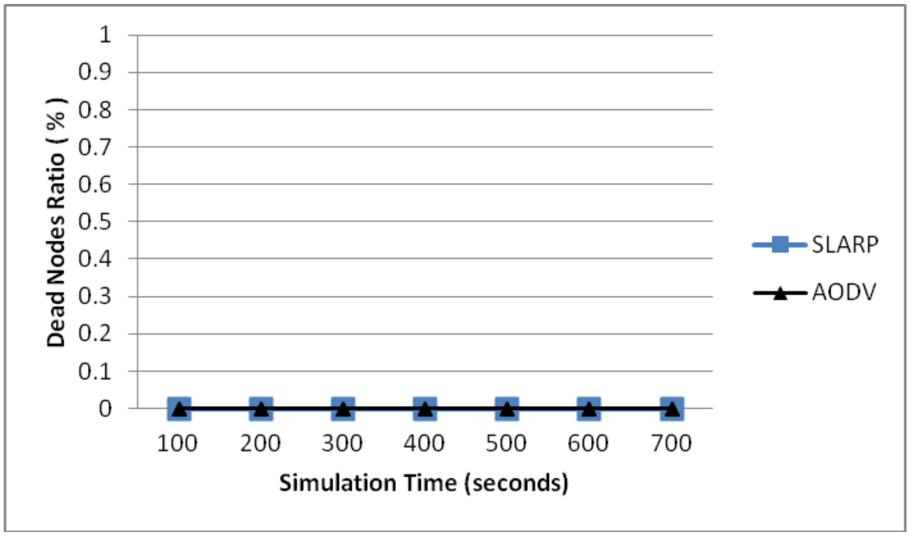

Figure 6.12: The dead nodes ratio of fifteen sources, each sends one packet per second.

6-2 The Average Lifetime of the Dead Nodes

In the light-load data traffic networks, such as network scenario that has five sources sending one packet per second, five sources sending two packets per second, ten sources sending one packet per second and fifteen sources sending one packet per second, there is no any dead node, due to their light-load traffic nature, wherein these scenarios' nodes do not require a large amount of energy to forward data. This is shown in the previous figures 6.9~6.12, where the number of dead nodes is zero for both SLARP and AODV.

The congestion causes depletion in the congested nodes energy and thus leads to the early death of the congested nodes. Moreover, an additional amount of energy will waste again to find a new route in the event of the death of an intermediate node. SLARP maintains the nodes energy and system lifetime as much as possible by distributing the data loads according to the residual energy amount and the congestions level of the intermediate nodes to avoid the congestion as much as possible. This justifies the superiority of SLARP over AODV in terms of the average lifetime of the dead nodes for all simulation time values that have any dead nodes. This is shown in figures 6.13~ 6.20 for the number of sources and transmission rates considered.

Figures 6.13 and 6.14, for example, show SLARP outperforms AODV by 100 percent when the simulation time value is 600 sec in network scenarios that have five sources sending four packets per second and ten sources sending two packets per second, where the simulation runs ended 600 sec without any dead nodes by using SLARP protocol, while some intermediate nodes are died by using AODV protocol.

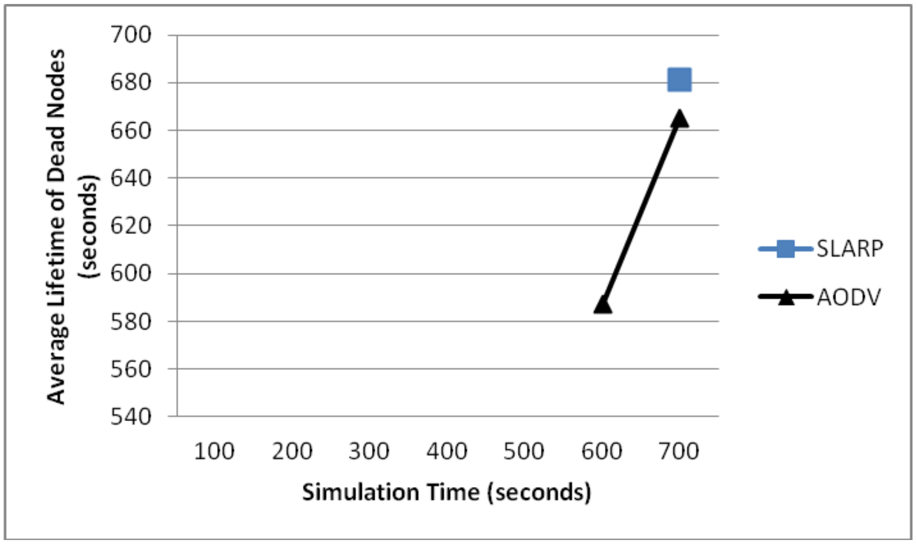

Figure 6.13: the average lifetime of the dead nodes of five sources, each sends four packets per second.

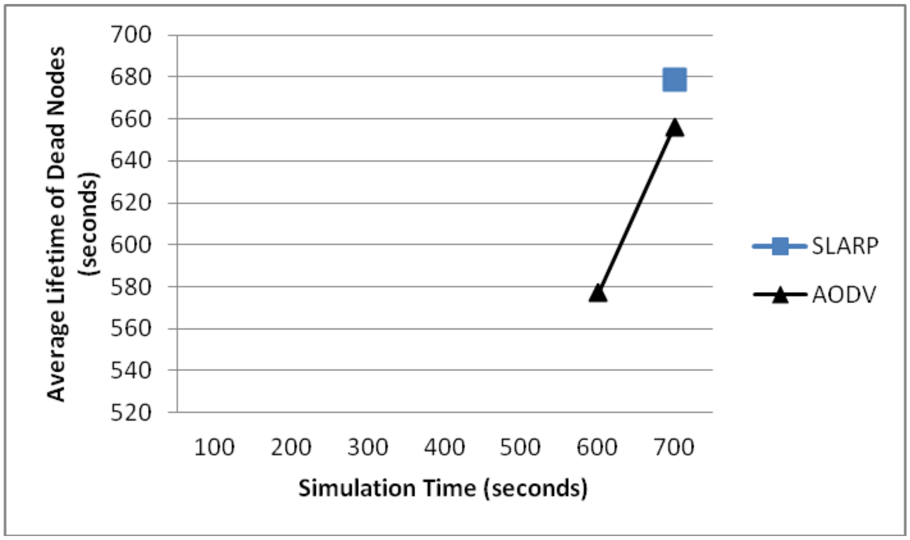

Figure 6.14: the average lifetime of the dead nodes of ten sources, each sends two packets per second.

In figure 6.15, SLARP outperforms AODV by 8.7, and 8.25 percent when the simulation time values are 600, and 700 secs, respectively. In figure 6.16, SLARP outperforms AODV by 12.87, 15.54, 14.54, and 12.28 percent when the simulation time values are 400, 500, 600, and 700 secs, respectively. In figure 6.17, SLARP outperforms AODV by 100, 21.87, 28.93, 27.70, and 25.74 percent when the simulation time values are 300, 400, 500, 600, and 700 secs, respectively, where there is no any dead node for SLARP when simulation time values are less than 300 sec.

In figure 6.18, SLARP algorithm outperforms AODV by 8.26, 10.33, and 8.09 percent when the simulation time values are 500, 600 and 700 secs, respectively. In figure 6.19, SLARP outperforms AODV by 100, 21.06, 23.20, 23.67, and 23.08 percent when the simulation time values are 300, 400, 500, 600, and 700 secs, respectively, where there is no any dead node for SLARP when simulation time values are less than 300 sec. In figure 6.20, SLARP outperforms AODV by 17.80, 21.43, 26.64, 24.95, and 21.93 percent when the simulation time values are 300, 400, 500, 600, and 700 secs, respectively.

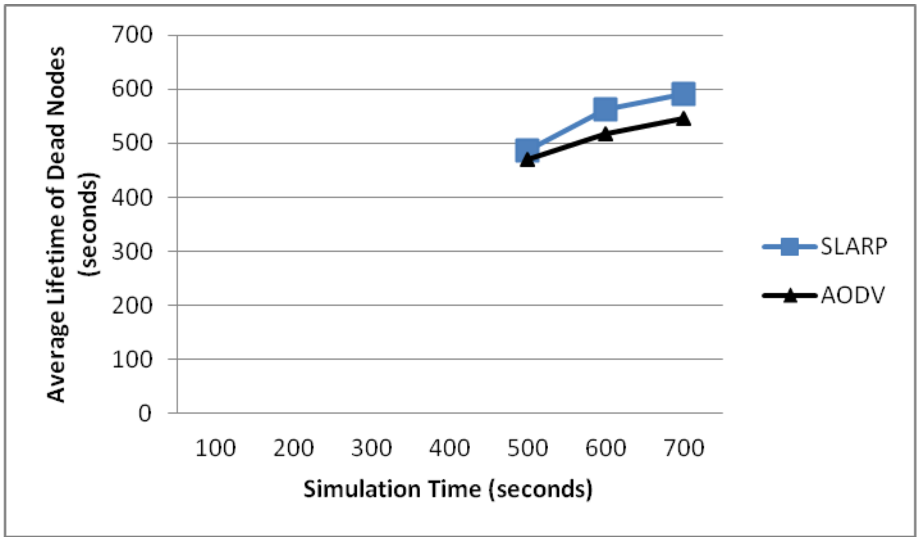

Figure 6.15: the average lifetime of the dead nodes of five sources, each sends six packets per second.

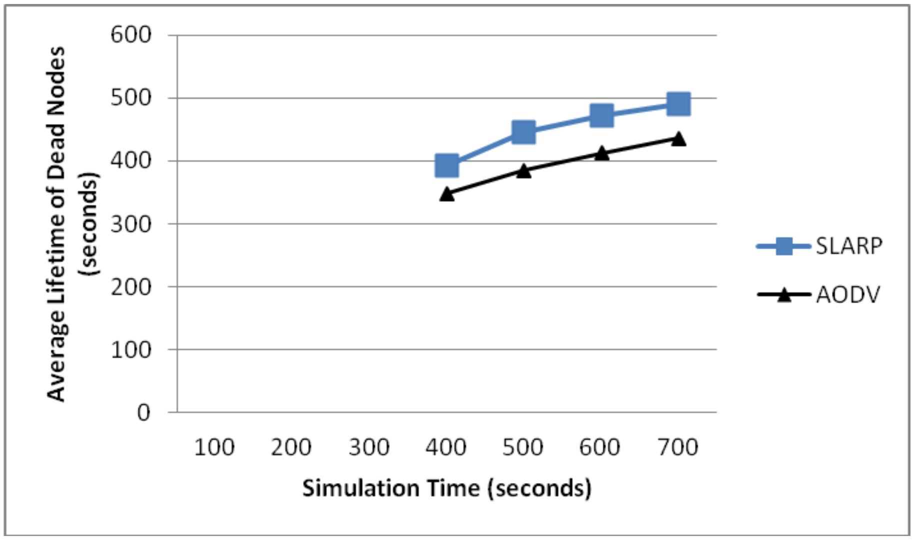

Figure 6.16: the average lifetime of the dead nodes of ten sources, each sends four packets per second.

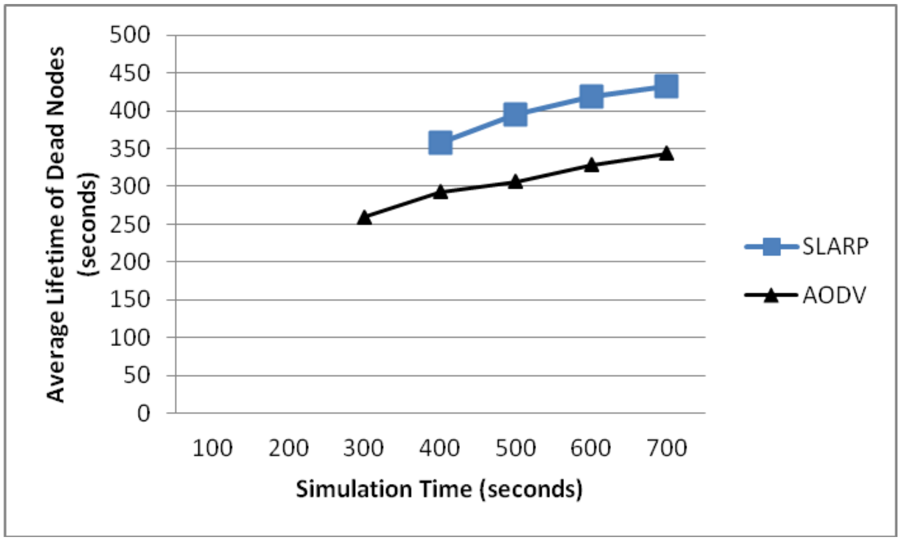

Figure 6.17: the average lifetime of the dead nodes of ten sources, each sends six packets per second.

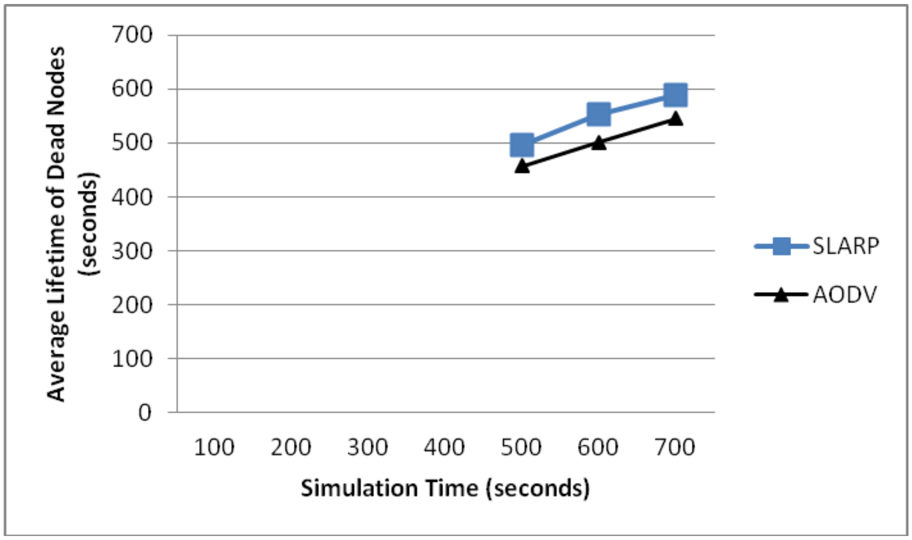

Figure 6.18: the average lifetime of the dead nodes of fifteen sources, each sends two packets per second.

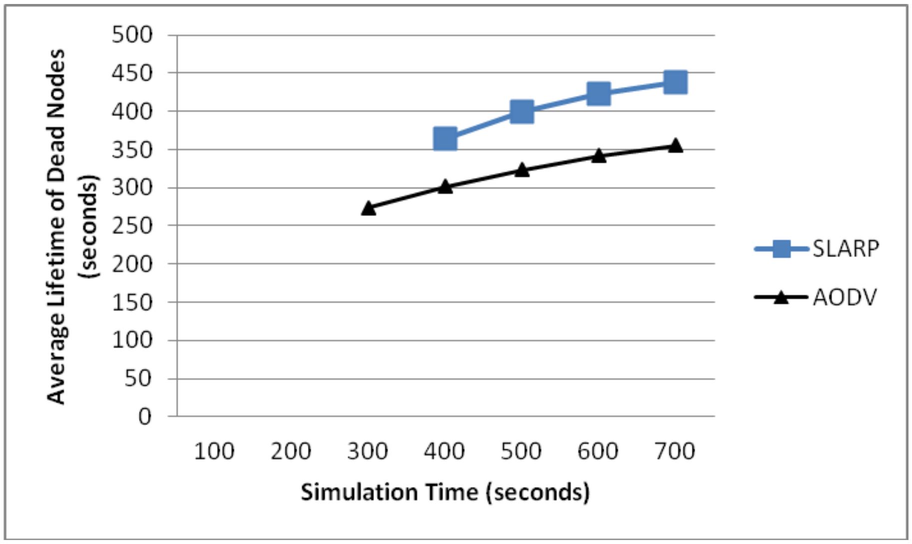

Figure 6.19: the average lifetime of the dead nodes of fifteen sources, each sends four packets per second.

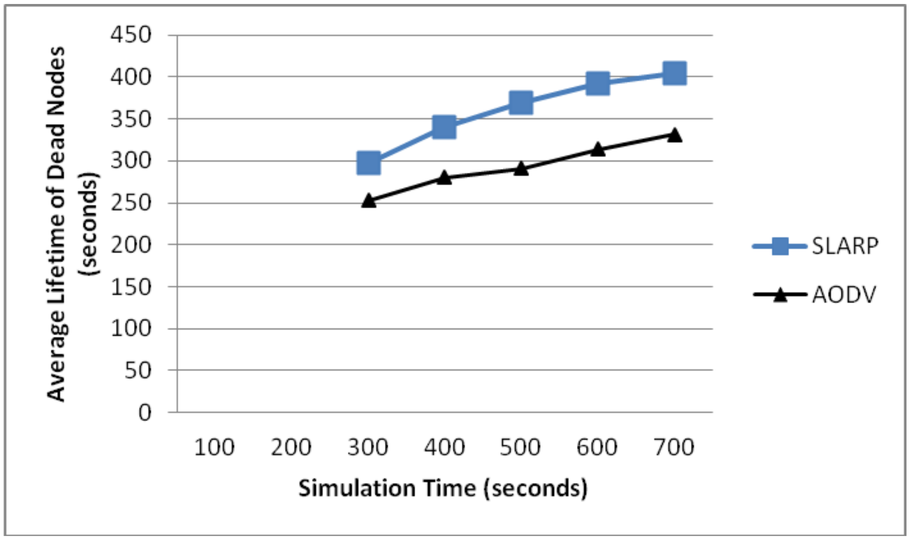

Figure 6.20: the average lifetime of the dead nodes of fifteen sources, each sends six packets per second.

6-3 Percentage of The Consumed Energy

SLARP maintains the nodes energy and the system lifetime as much as possible by distributing the traffic loads according to the residual energy amount and the congestions level of the intermediate nodes in order to avoid the congestion as much as possible, thus reduces the probability of the death of an intermediate nodes and subsequently no need for more energy to do routes maintenance. This justifies the superiority of SLARP over AODV in terms of percentage of consumed energy for all simulation time values. This is shown in the figures 6.21~6.32 for all number of sources and transmission rates considered.

Figure 6.21, for example, SLARP algorithm outperforms AODV by 41.12, 34.28, 15.90, 15.44, 9.89, and 12.29 percent when the simulation time values are 200, 300, 400, 500, 600, and 700 secs, respectively.

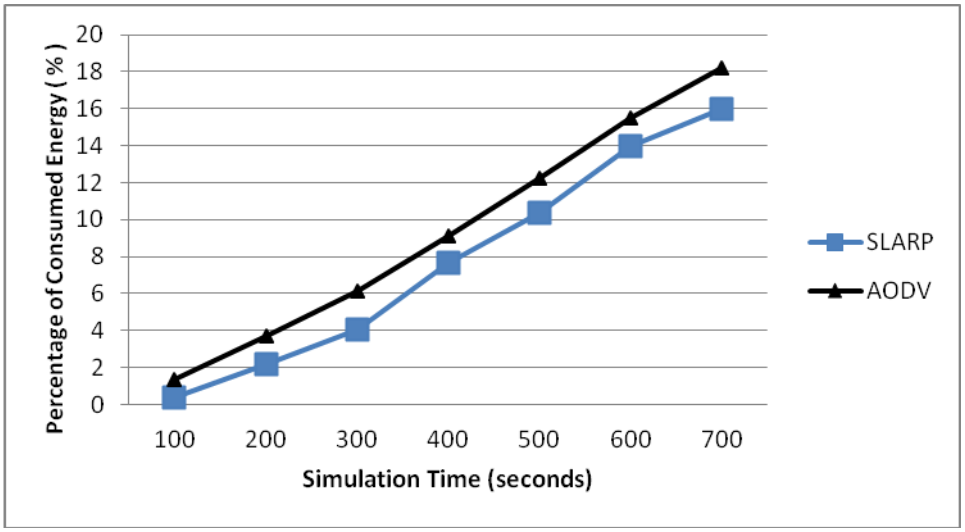

Figure 6.21: the percentage of consumed energy of five sources, each sends one packet per second.

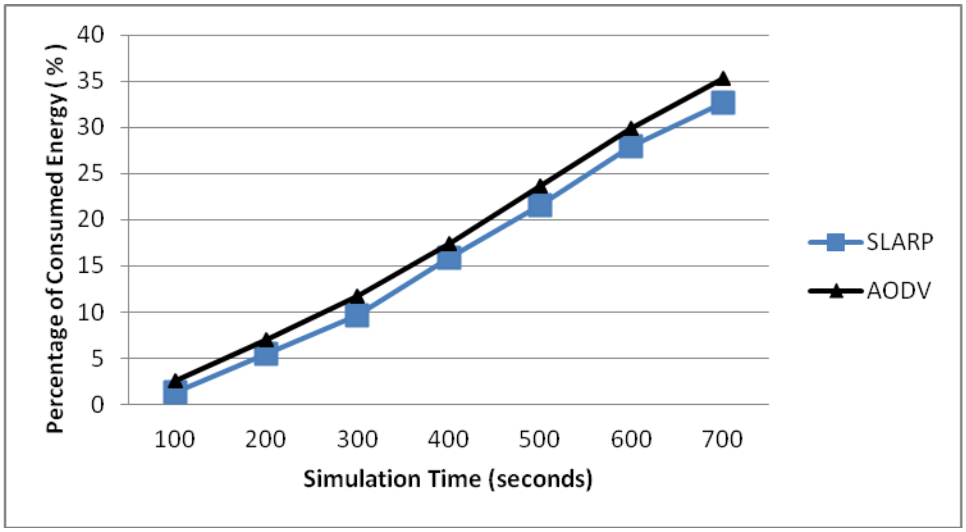

Figure 6.22: the percentage of consumed energy of five sources, each sends two packets per second.

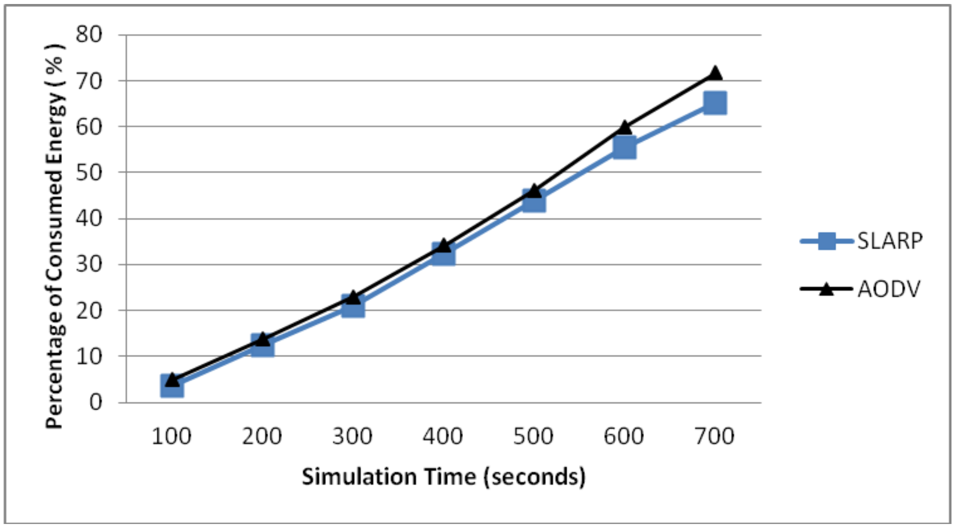

Figure 6.23: the percentage of consumed energy of five sources, each sends four packets per second.

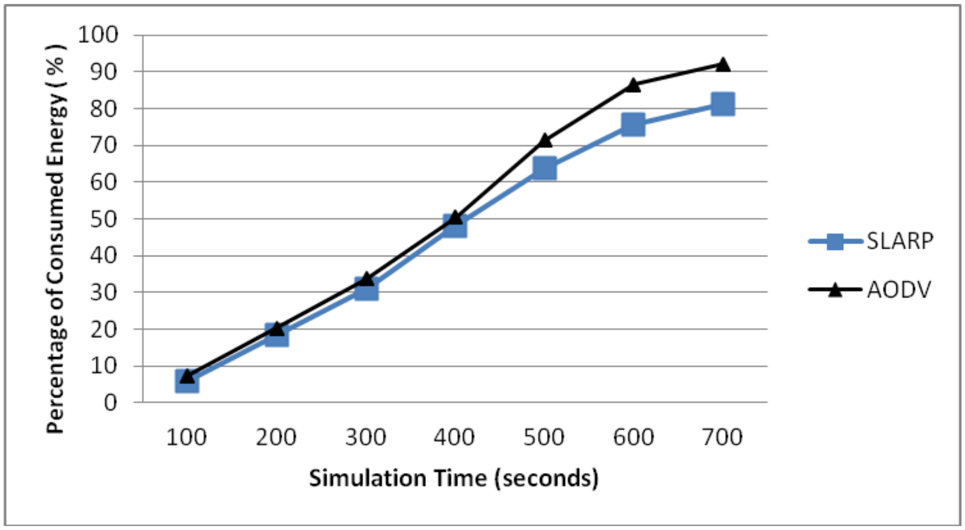

Figure 6.24: the percentage of consumed energy of five sources, each sends six packets per second.

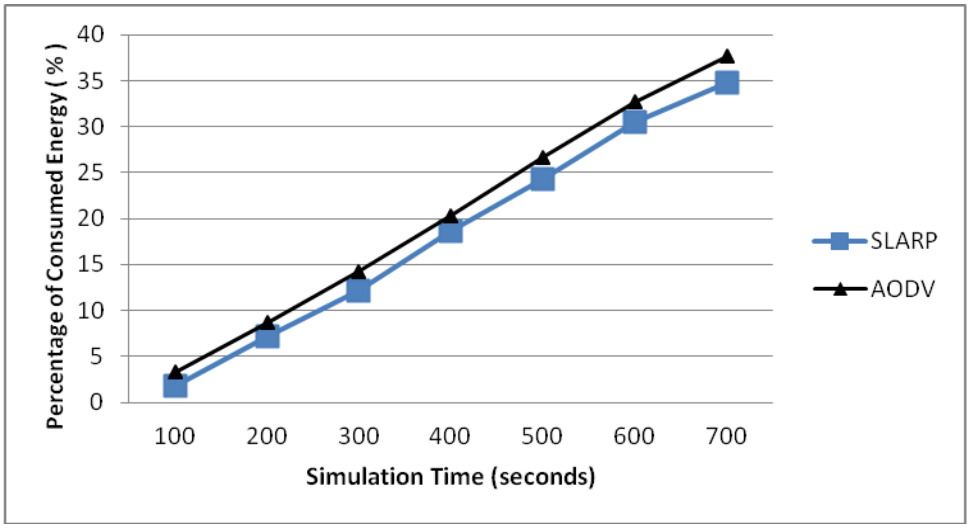

Figure 6.25: the percentage of consumed energy of ten sources, each sends one packet per second.

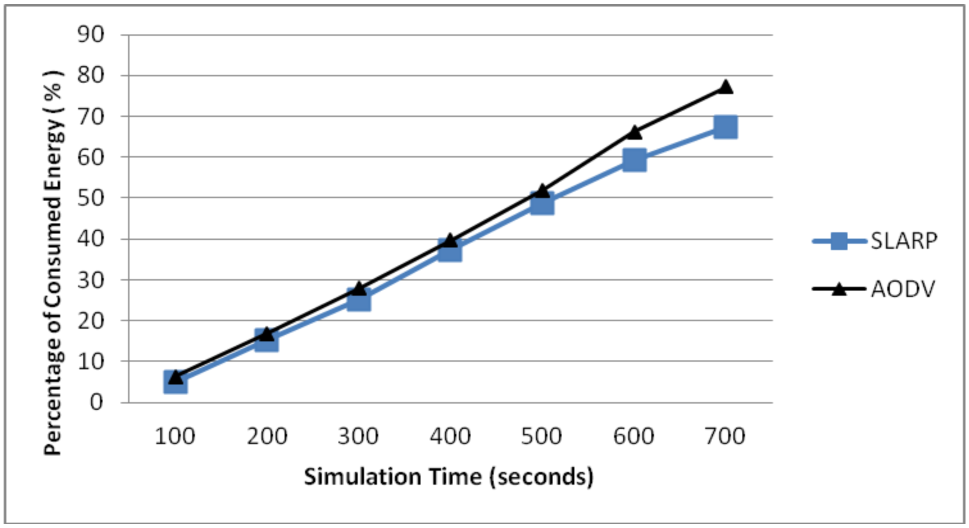

Figure 6.26: the percentage of consumed energy of ten sources, each sends two packets per second.

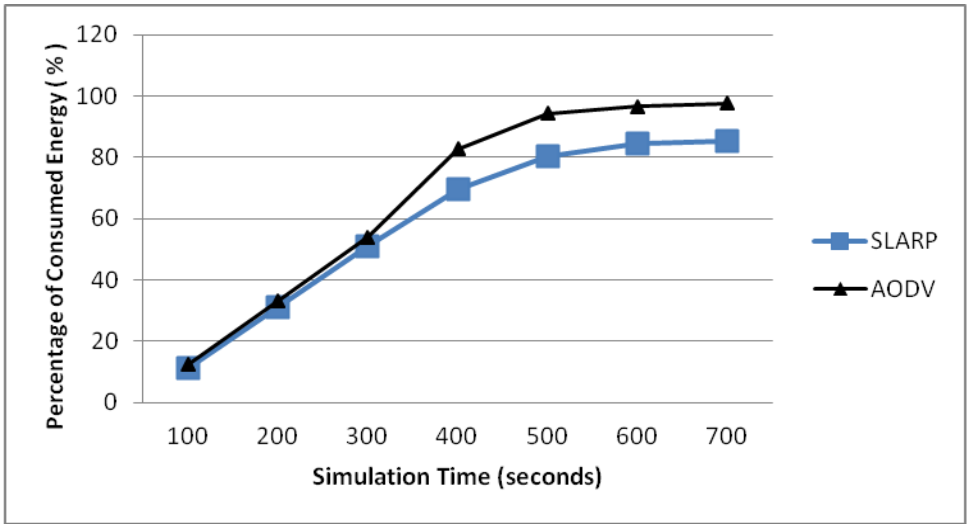

Figure 6.27: the percentage of consumed energy of ten sources, each sends four packets per second.

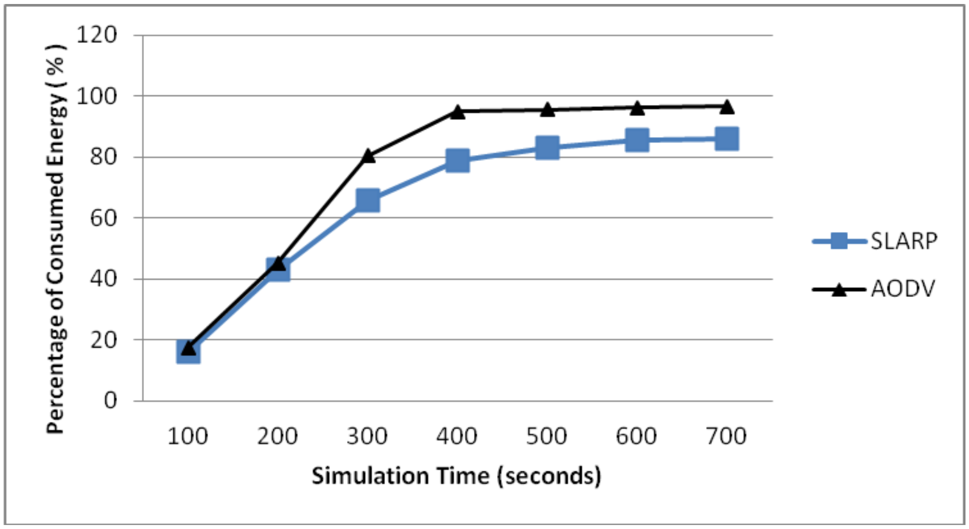

Figure 6.28: the percentage of consumed energy of ten sources, each sends six packets per second.

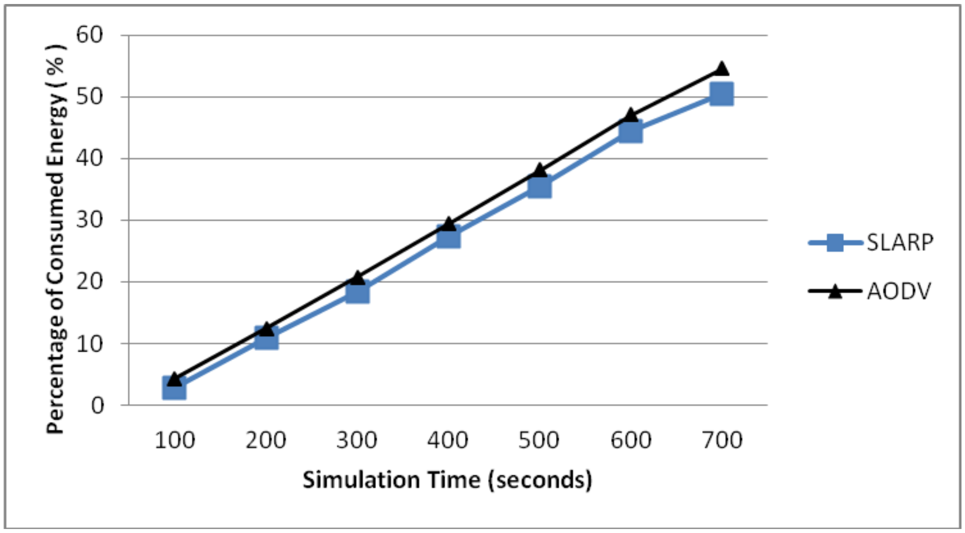

Figure 6.29: the percentage of consumed energy of fifteen sources, each sends one packet per second.

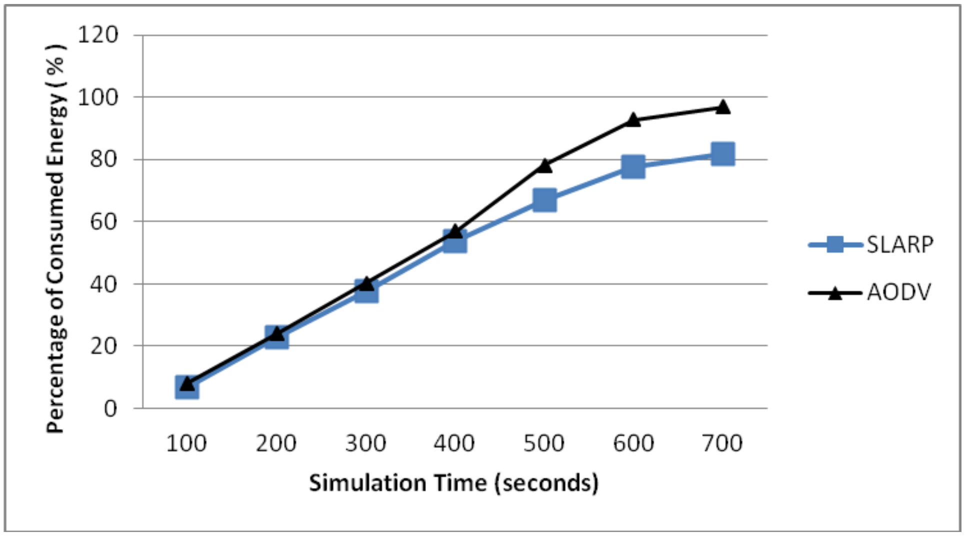

Figure 6.30: the percentage of consumed energy of fifteen sources, each sends two packets per second.

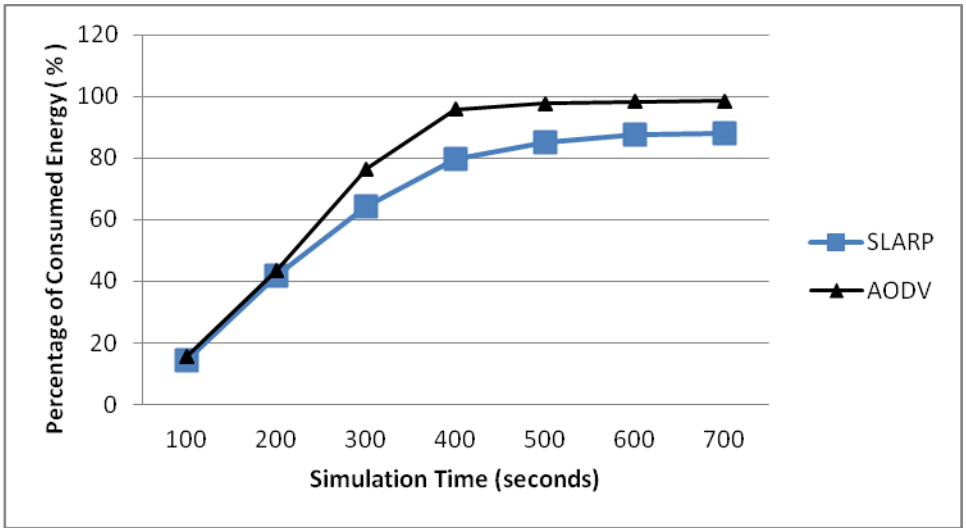

Figure 6.31: the percentage of consumed energy of fifteen sources, each sends four packets per second.

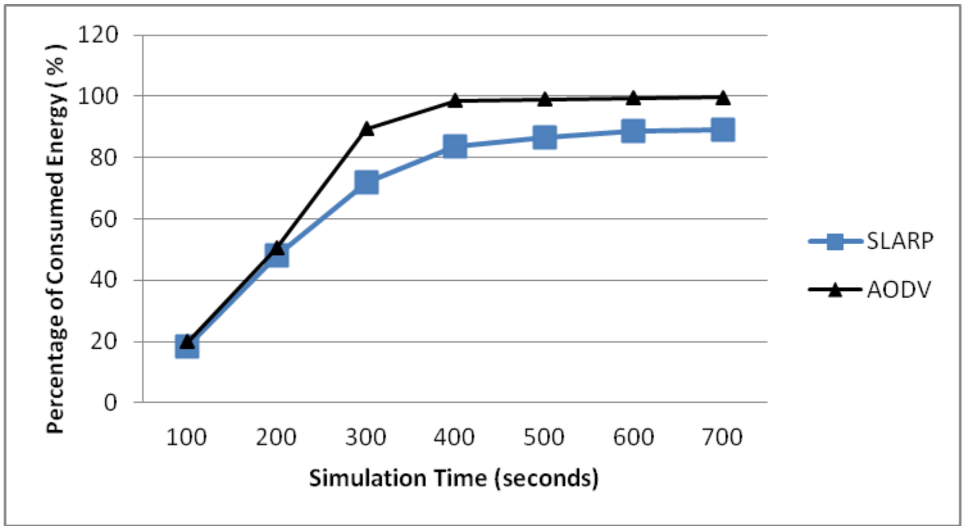

Figure 6.32: the percentage of consumed energy of fifteen sources, each sends six packets per second.

6-4 Packet Delivery Ratio (PDR)

A network scenario called a light data traffic network when it has a small number of sources like five sources or it has a small data transmission rate like sending one packet per second. Whereas it is called a heavy data traffic network when it has a large number of sources that are sending data at a high transmission rate like fifteen or ten sources that are sending four or six packets per second.

Figures 6.33~6.39 show the packet delivery ratio for different transmission rate values and a different number of sources. The simulation results in these figures show that SLARP and AODV exhibit superior performance (more than 90%) and they are fairly close to each other in all simulation time values for a light data traffic network scenarios. This is because, in such networks, there is a low level of congestion and thus a small number of packets are dropped.

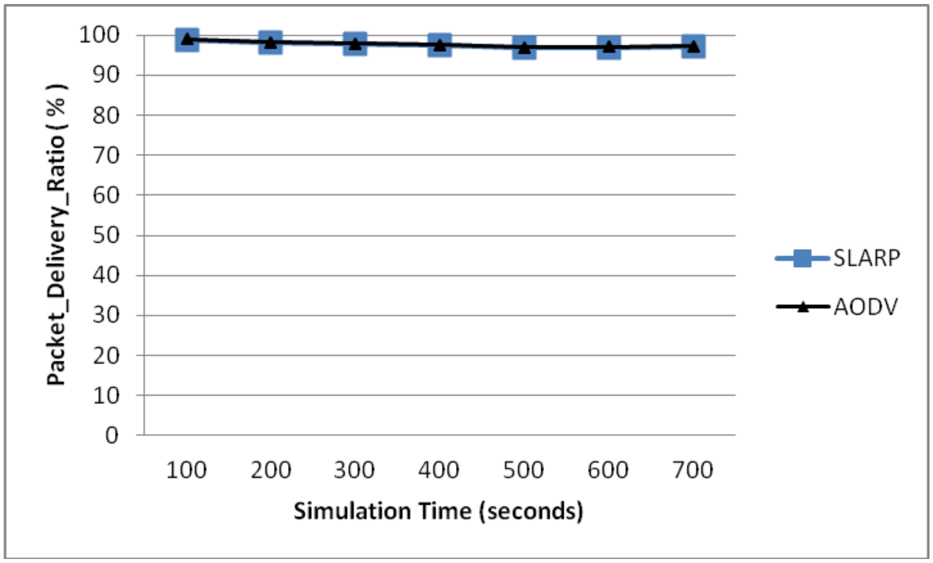

Figure 6.33: The delivery ratio of five sources, each sends one packet per second.

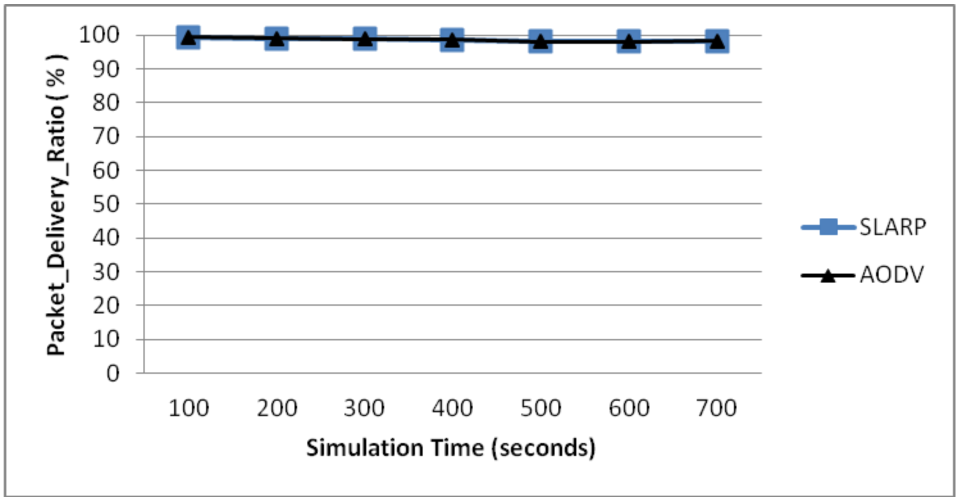

Figure 6.34: The delivery ratio of five sources, each sends two packets per second.

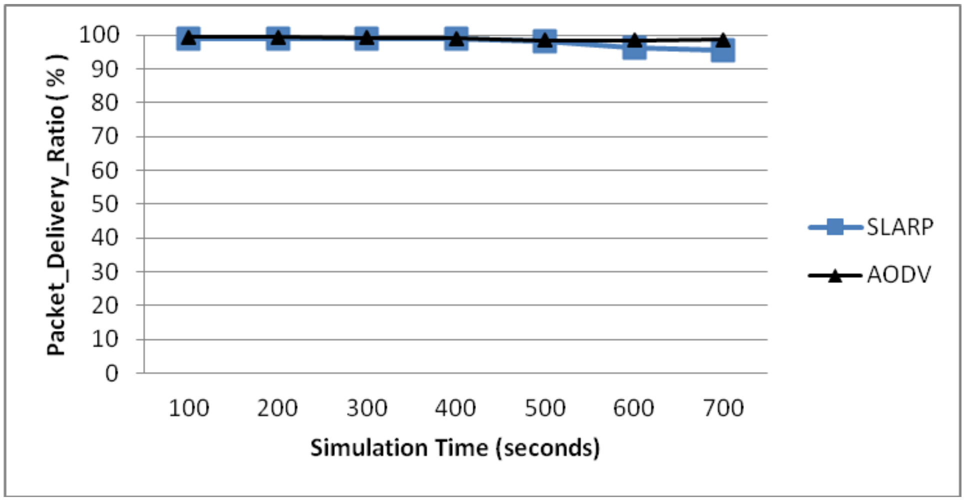

Figure 6.35: The delivery ratio of five sources, each sends four packets per second.

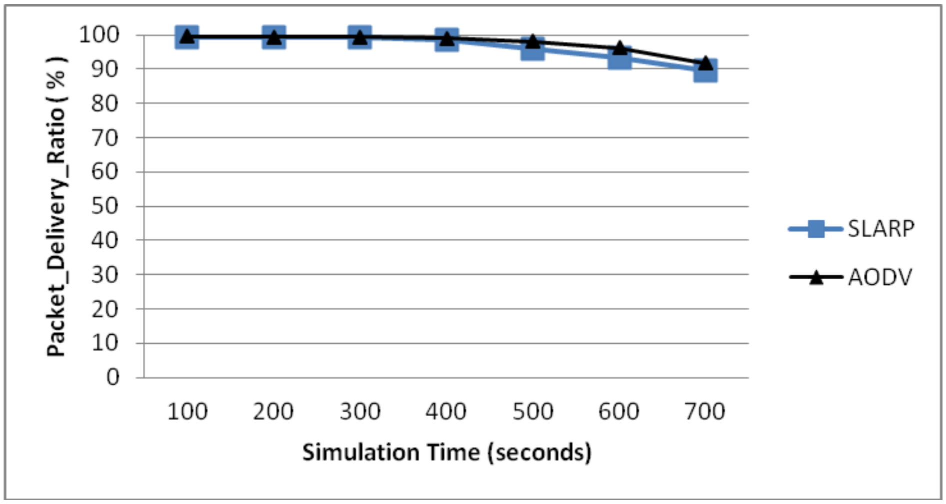

Figure 6.36: The delivery ratio of five sources, each sends six packets per second.

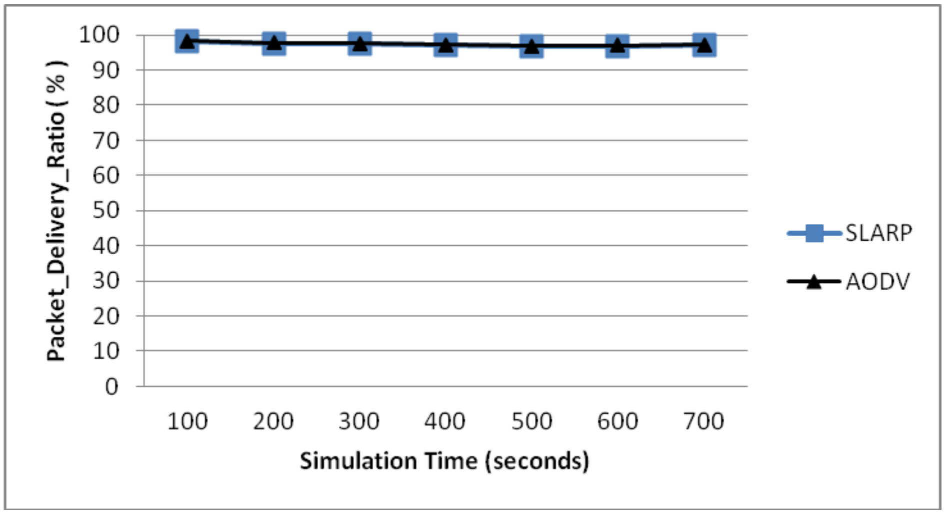

Figure 6.37: The delivery ratio of ten sources, each sends one packet per second.

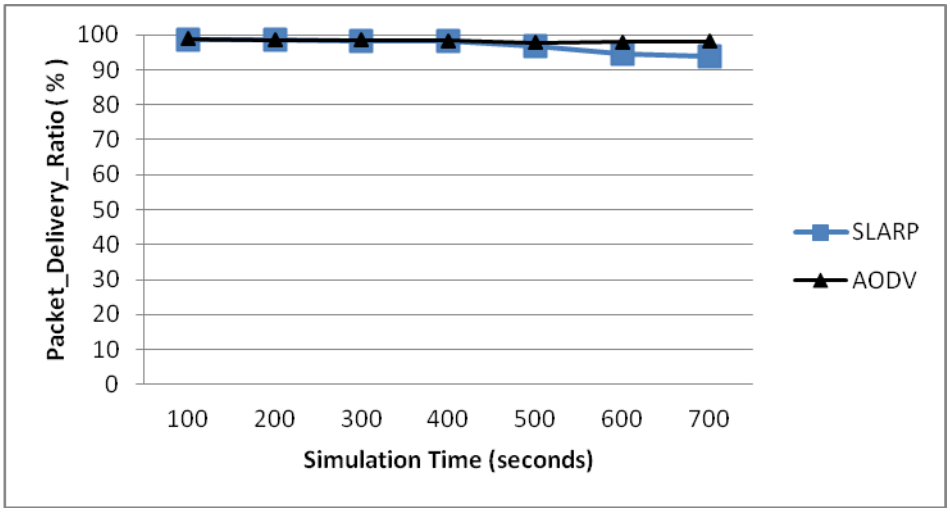

Figure 6.38: The delivery ratio of ten sources, each sends two packets per second.

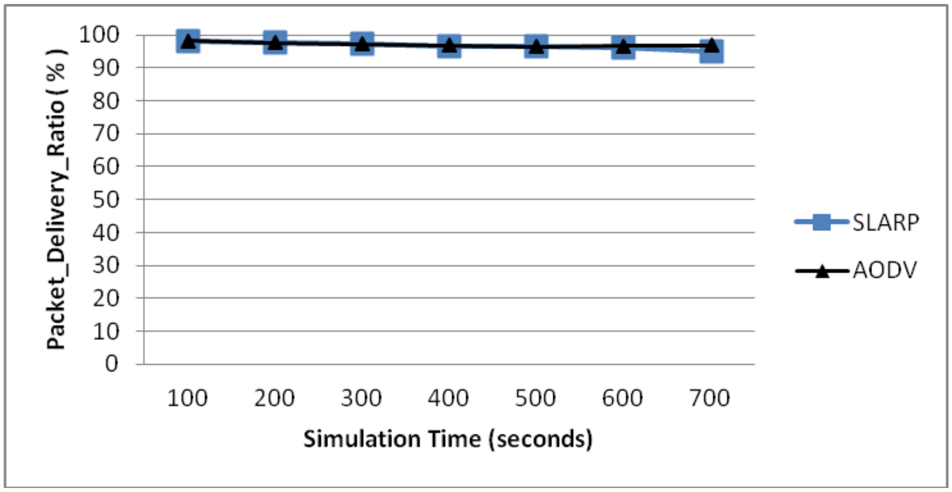

Figure 6.39: The delivery ratio of fifteen sources, each sends one packet per second.

Figures 6.40~6.44 show the packet delivery ratio for different transmission rate values and a different number of sources under heavy data traffic network scenarios for both protocols SLARP and AODV. The simulation results for these figures shows a non-influential decline of the packets delivery ratio of SLARP when the simulation time values are 500, 600 and 700 sec. which is occurred because SLARP continues sending data for a time more than that of AODV due to the abundance in the lifetime and the energy of the intermediate nodes that provided by SLARP, which reflects the superiority of SLARP over AODV in terms of throughput, as shown in figures 6.40 and 6.66, for example. Where figure 6.40 shows the packets delivery ratio for the SLARP and AODV protocols when the number of sources is fifteen and the transmission rate is two packets per second. And figure 6.66 shows the throughput of the two protocols for the same network scenario.

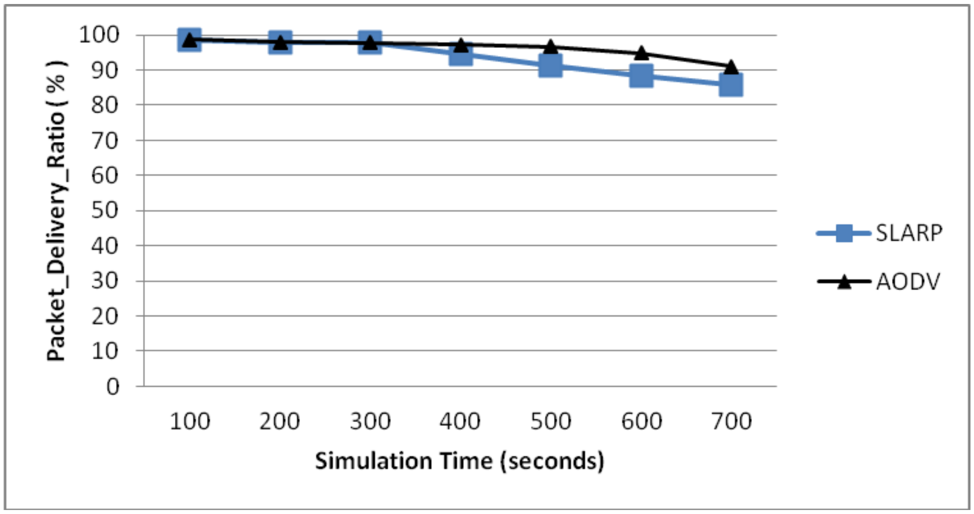

Figure 6.40: The delivery ratio of fifteen sources, each sends two packets per second.

The simulation results for figures 6.41~6.44 show that the packets delivery ratio for SLARP and AODV is fairly does not exceed 90%. This decline in packets delivery ratio is caused by the high transmission rate, which increases the occurrence of congestion and dropping more packets by the intermediate nodes. The SLARP and AODV algorithms use the same mechanism and policy in delivering the packets, so their performance in terms of packet delivery ratio is close to each other.

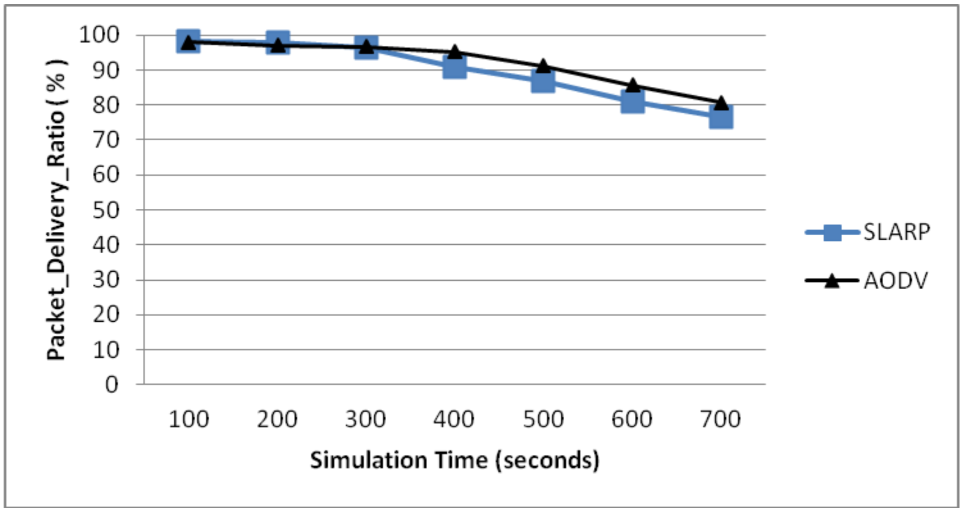

Figure 6.41: The delivery ratio of ten sources, each sends four packets per second.

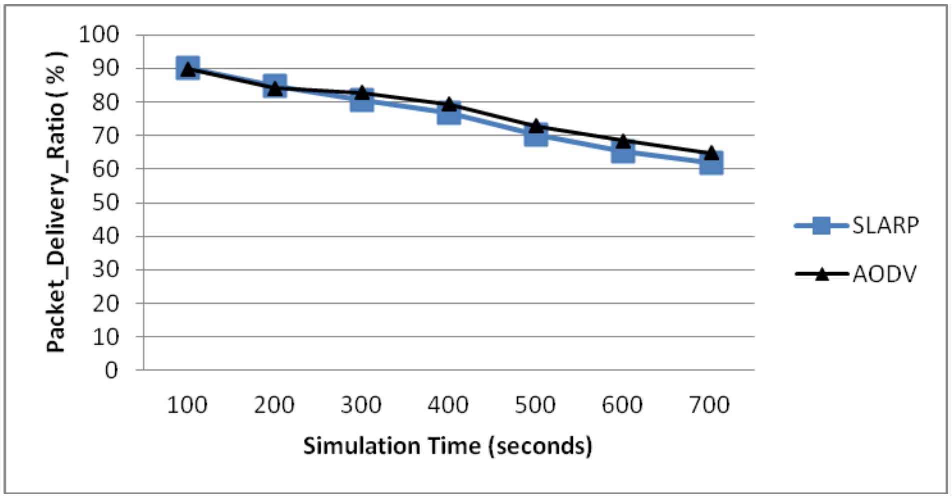

Figure 6.42: The delivery ratio of ten sources, each sends six packets per second.

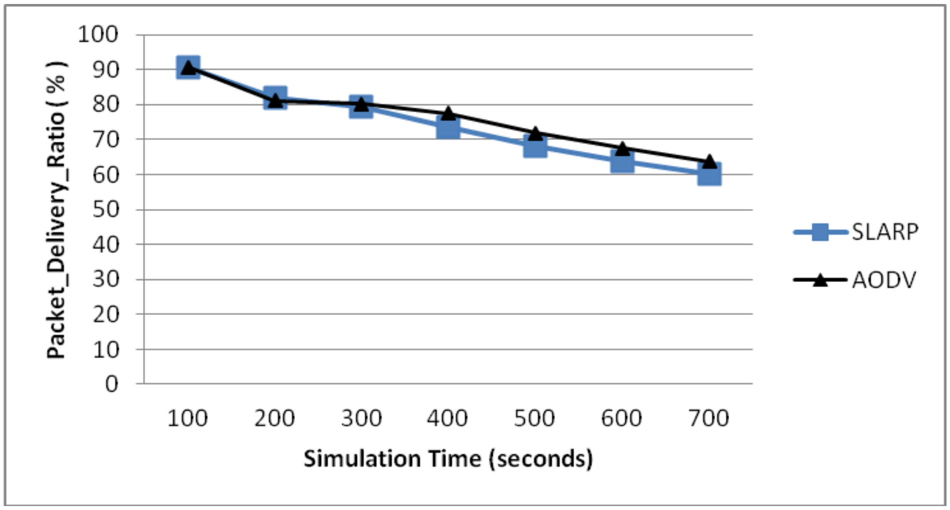

Figure 6.43: The delivery ratio of fifteen sources, each sends four packets per second.

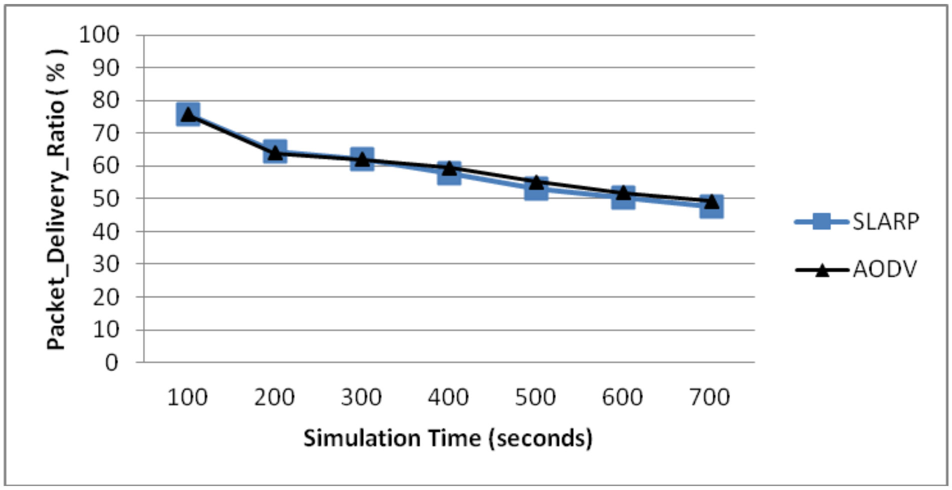

Figure 6.44: The delivery ratio of fifteen sources, each sends six packets per second.

6-5 Average End-to-End Delay

Figures 6.45~6.52 show the performance of the SLARP and AODV algorithms in terms of end-to-end delay for a different number of sources and different values for transmission rate. It can be seen in these figures that SLARP made a significant improvement in reducing the average end-to-end delay as compared with the original AODV. This is due to the load distribution mechanism used by SLARP to avoid the congested nodes and reduce the congested as well, thus packets do not need to wait for a long time in the interfaces queue of the intermediate nodes to send out. This makes SLARP superior in terms of end-to-end delay as compared to the AODV protocol. In figure 6.45, for example, SLARP algorithm outperforms AODV by 19.36, 11.21, 28.19, 38.25, 35.25, 24.32, and 31.11 percent when the simulation time values are 100, 200, 300, 400, 500, 600, and 700 secs, respectively.

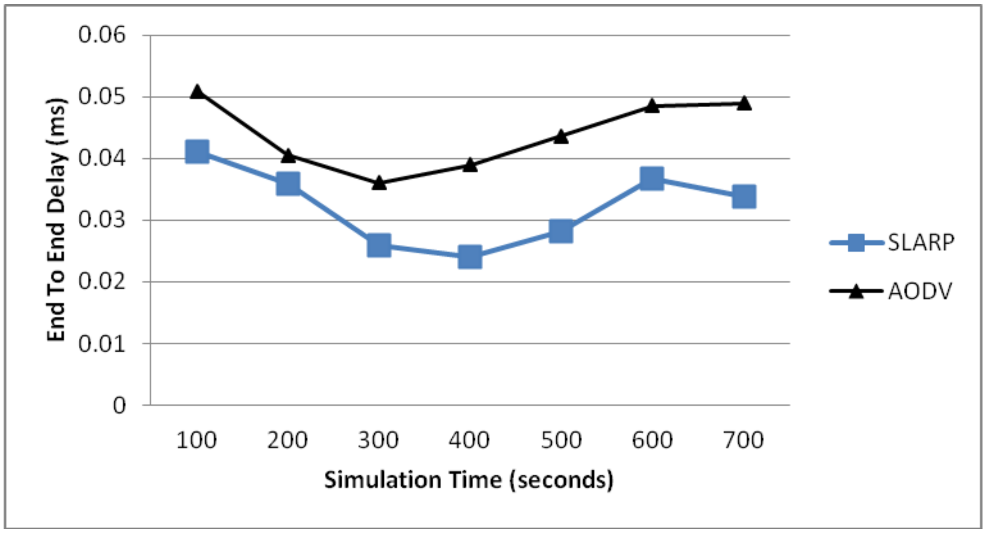

Figure 6.45: The average end-to-end delay of five sources, each sends one packet per second.

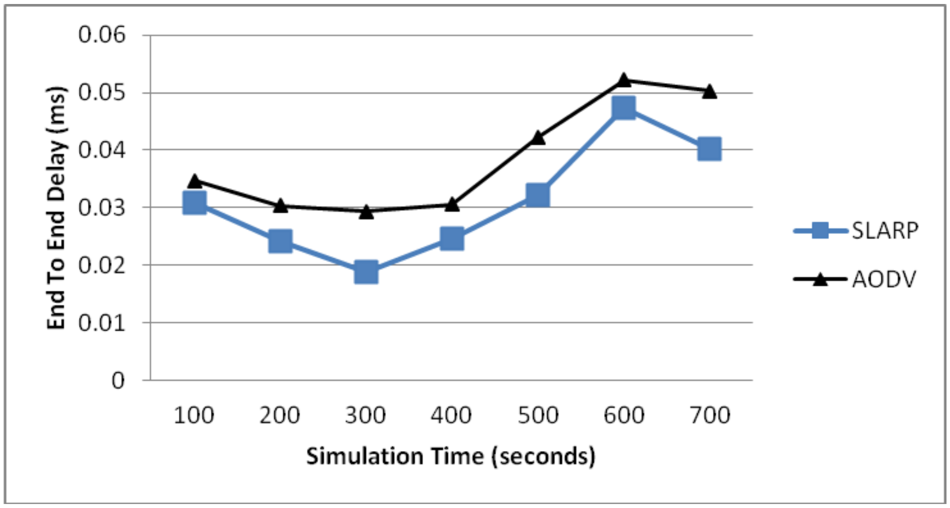

Figure 6.46: The average end-to-end delay of five sources, each sends two packets per second.

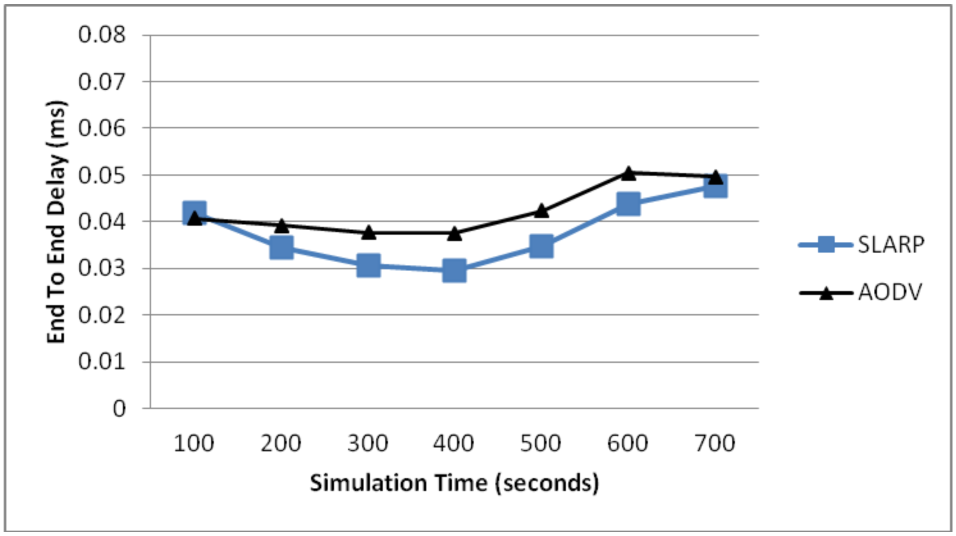

Figure 6.47: The average end-to-end delay of five sources, each sends four packets per second.

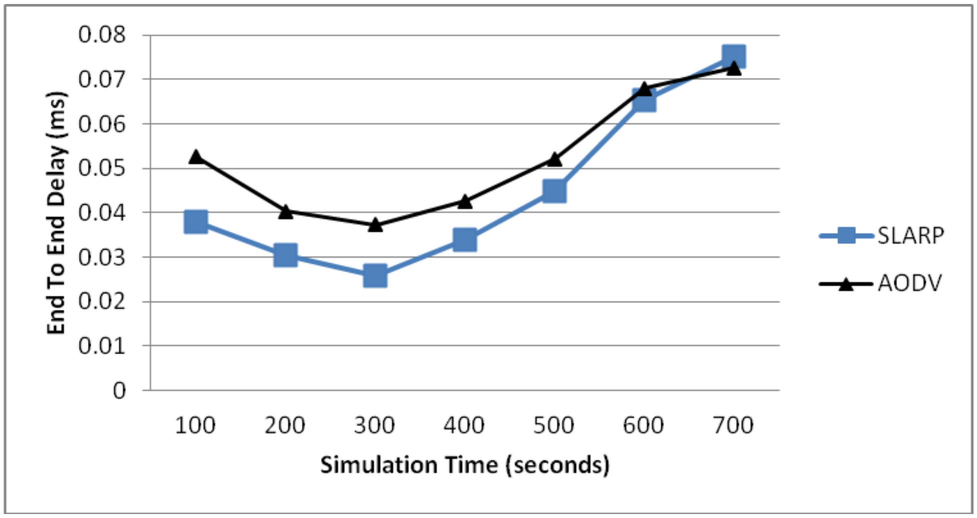

Figure 6.48: The average end-to-end delay of five sources, each sends six packets per second.

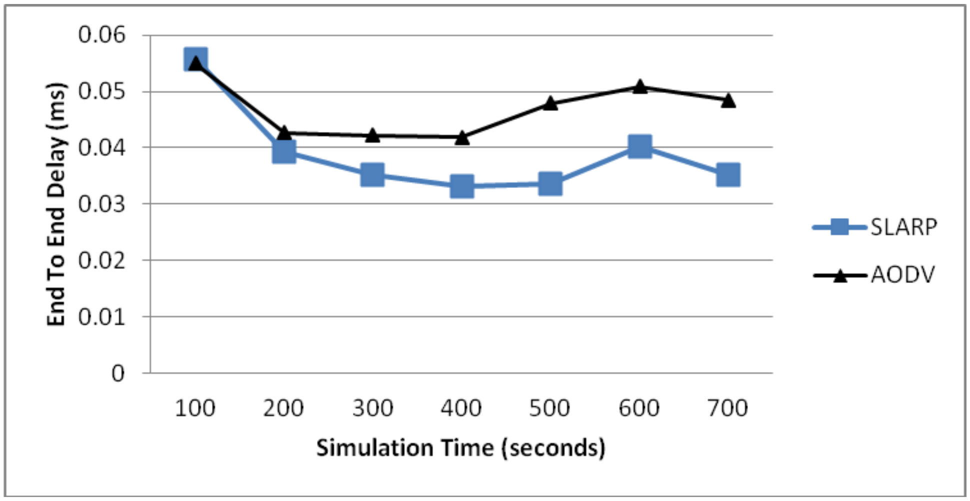

Figure 6.49: The average end-to-end delay of ten sources, each sends one packet per second.

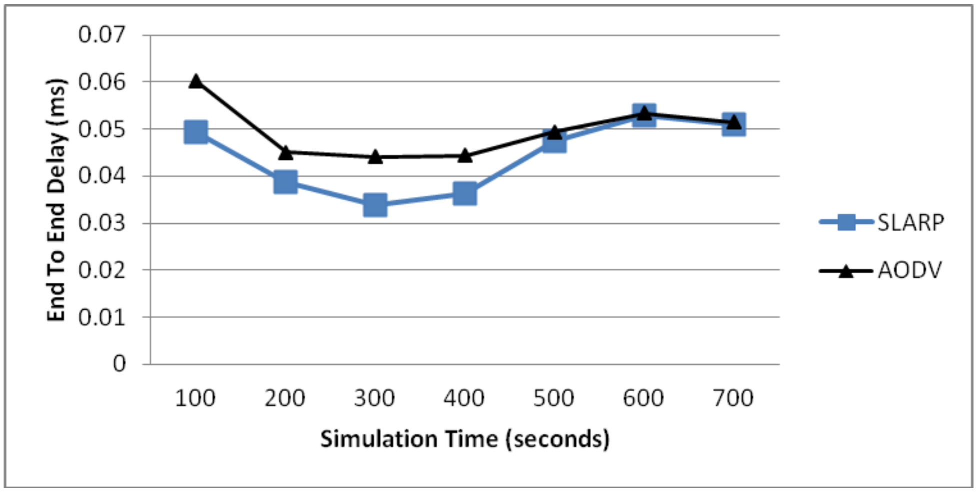

Figure 6.50: The average end-to-end delay of ten sources, each sends two packets per second.

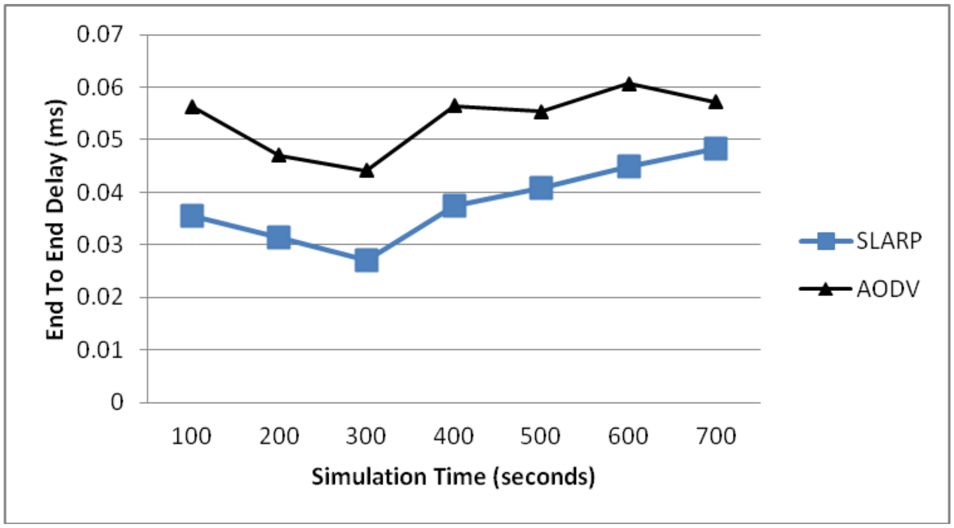

Figure 6.51: The average end-to-end delay of fifteen sources, each sends one packet per second.

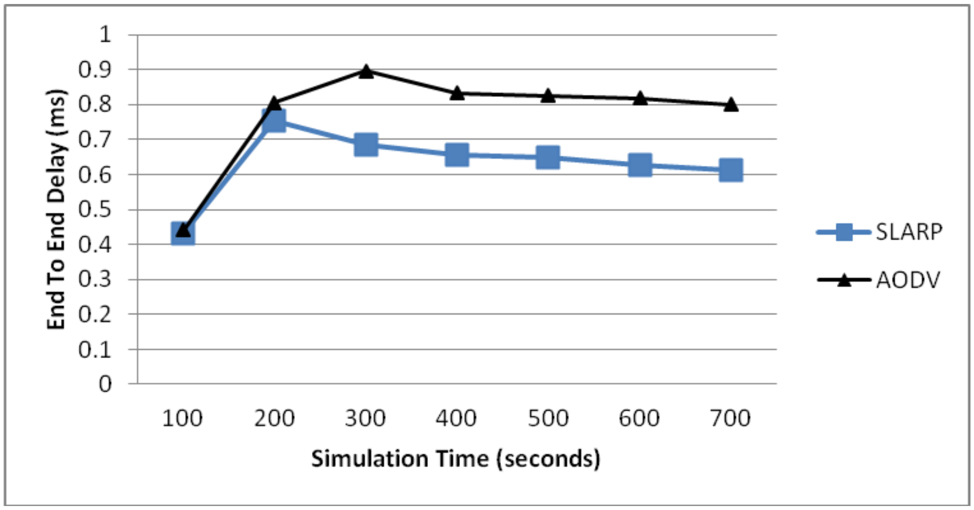

Figure 6.52: The average end-to-end delay of fifteen sources, each sends six packets per second.

As previously explained, SLARP selects the required routes according to the residual energy amount and the congestion level of the intermediate nodes that plays an important role in order to reduce the average end-to-end delay, especially in the simulation time values that are less than 400 seconds, where the number of the dead nodes is the lowest possible value. This is shown in all figures of this section. But in some cases, as shown in figures 6.53~6.56 for the number of sources and transmission rates considered, when the simulation lasts for the longest time, more nodes are being died, and hence the choices to choose a route become limited, and as a result the performance of AODV is better than that of SLARP. It can be seen in figure 6.55, for example, SLARP outperforms AODV by 6.64, 21.44, 19.52, and 8.91 percent when the simulation time values are 100, 200, 300, and 400 secs, respectively. Nevertheless, AODV outperforms SLARP by 3.66, 5.02, and 7.33 percent when the simulation time values are 500, 600, and 700 secs, respectively. This is because SLARP continues sending data for a time more than that of AODV due to the abundance in the lifetime and the energy of the intermediate nodes that provided by SLARP, which reflects the superiority of SLARP over AODV in terms of throughput as shown in figure 6.66.

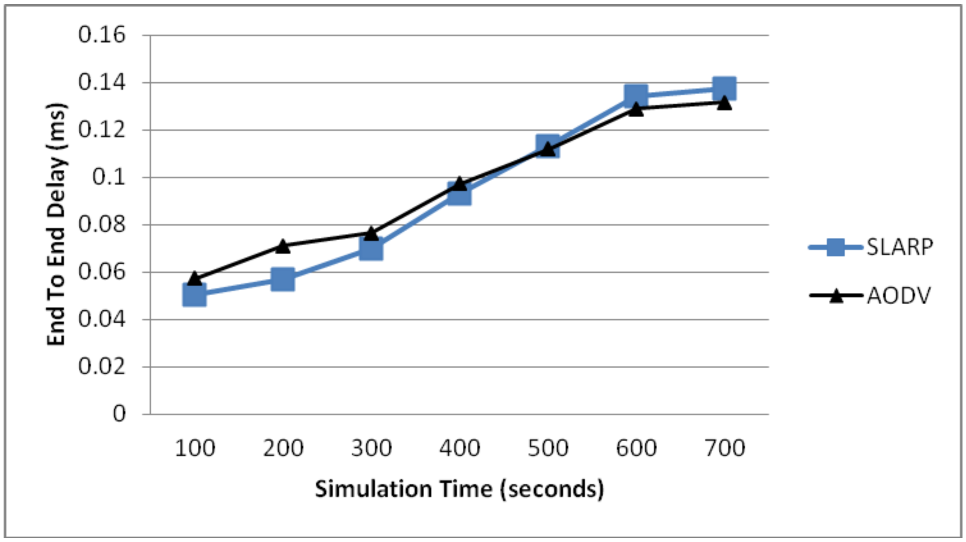

Figure 6.53: The average end-to-end delay of ten sources, each sends four packets per second.

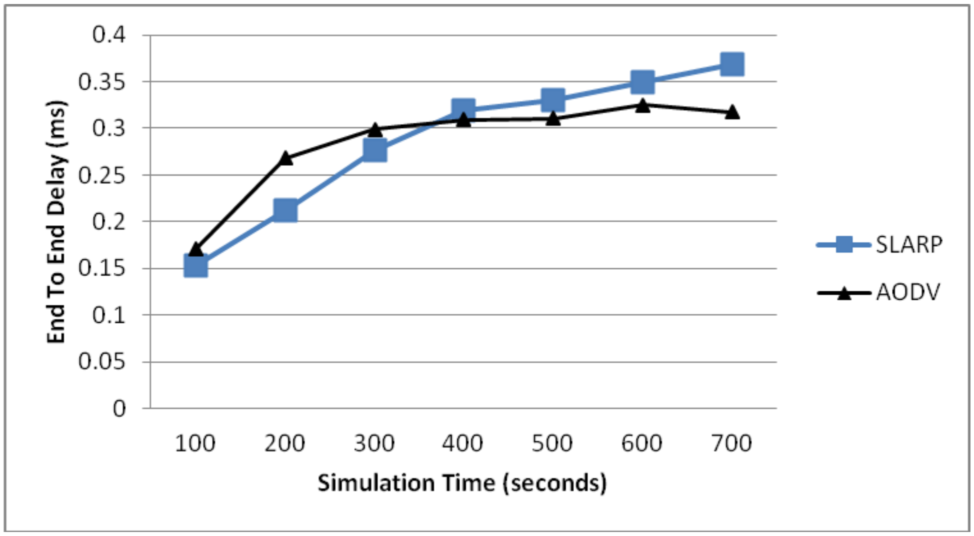

Figure 6.54: The average end-to-end delay of ten sources, each sends six packets per second.

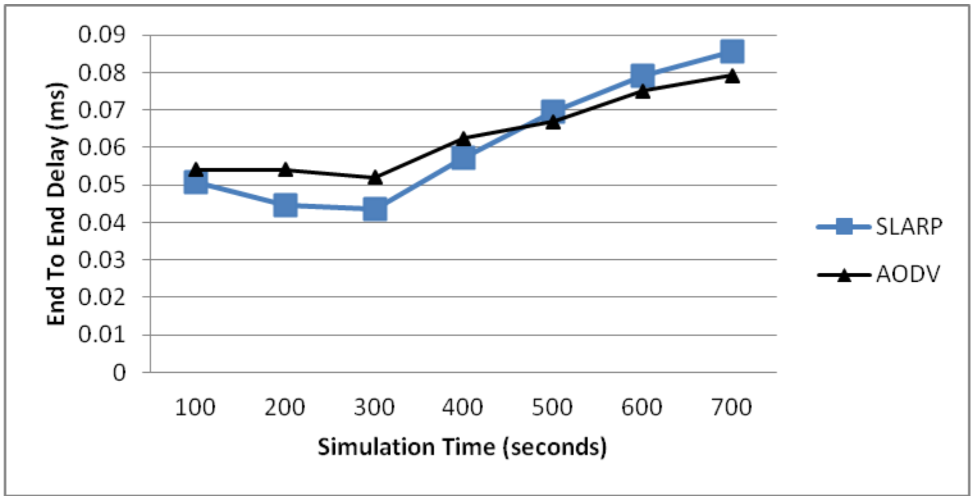

Figure 6.55: The average end-to-end delay of fifteen sources, each sends two packets per second.

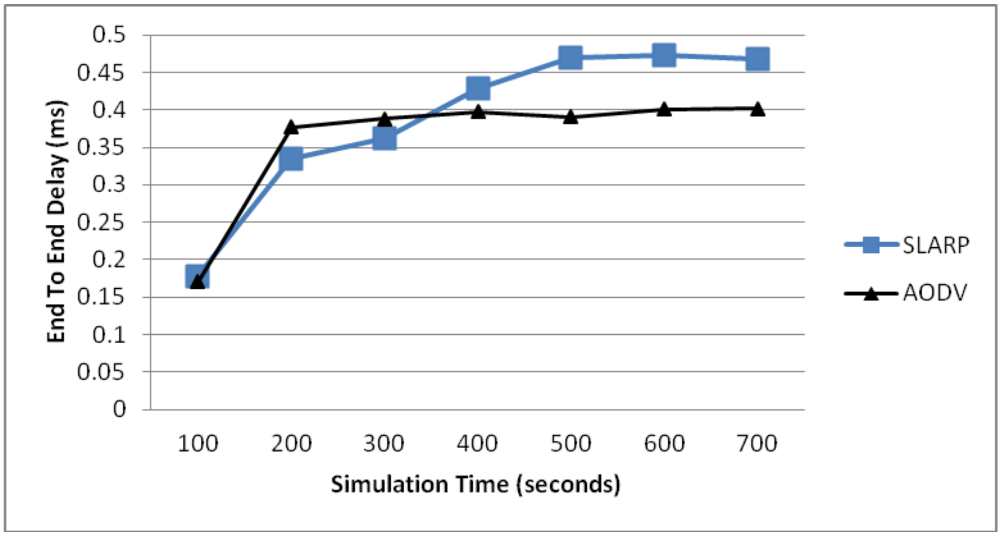

Figure 6.56: The average end-to-end delay of fifteen sources, each sends four packets per second.

6-6 Throughput

Figures 6.57~6.63 show that the throughput for SLARP and AODV are fairly close to each other in all simulation time values and different number of sources under different transmission time values, this is because these network scenarios are not suffering from a high level of congestion or excessive draining in nodes energy due to the light-load of the data traffic.

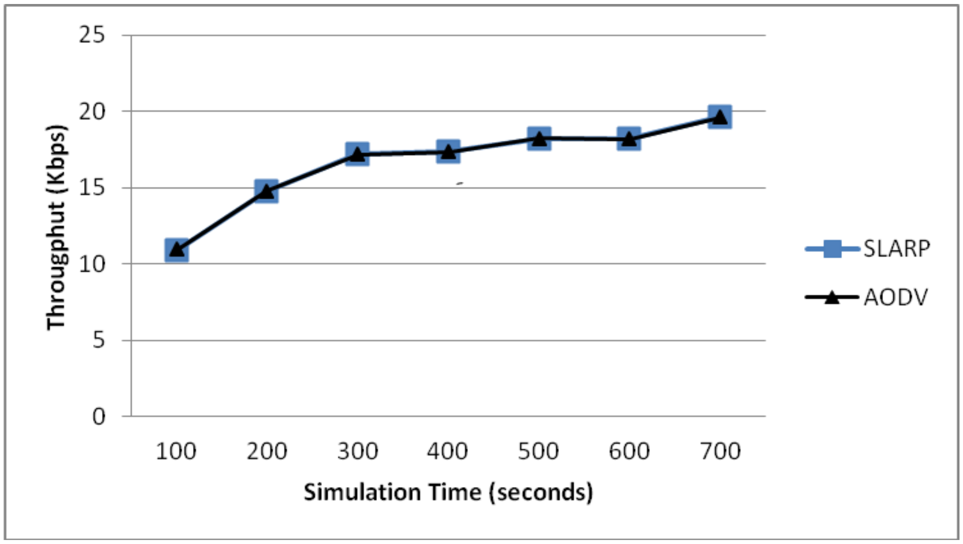

Figure 6.57: The throughput of five sources, each sends one packet per second.

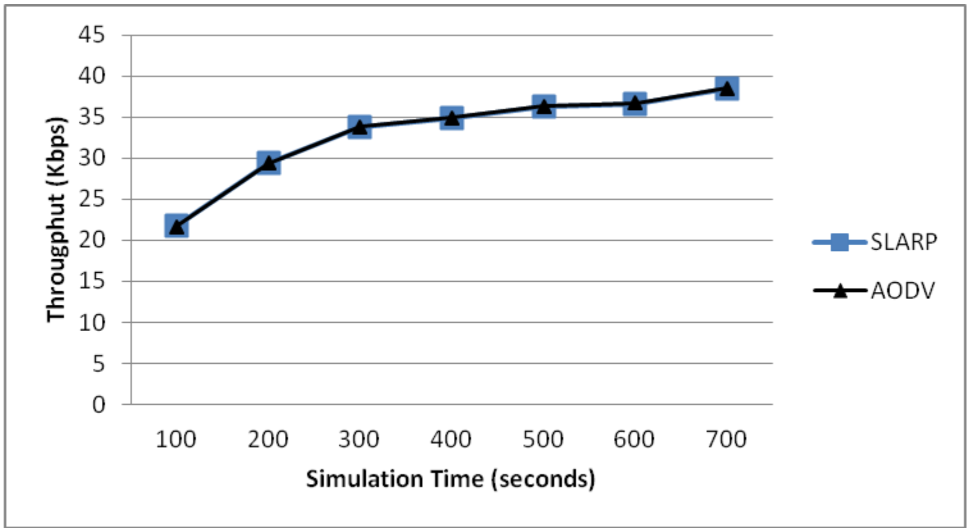

Figure 6.58: The throughput of five sources, each sends two packets per second.

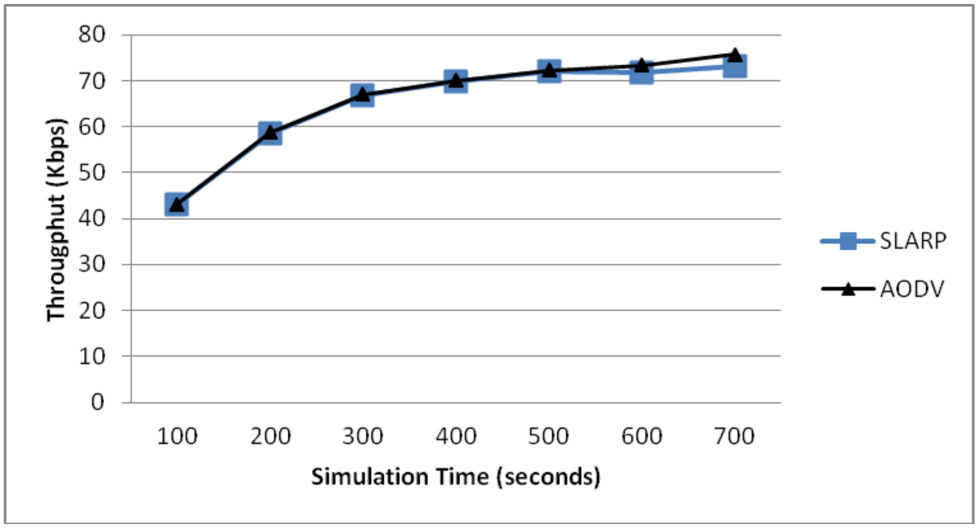

Figure 6.59: The throughput of five sources, each sends four packets per second.

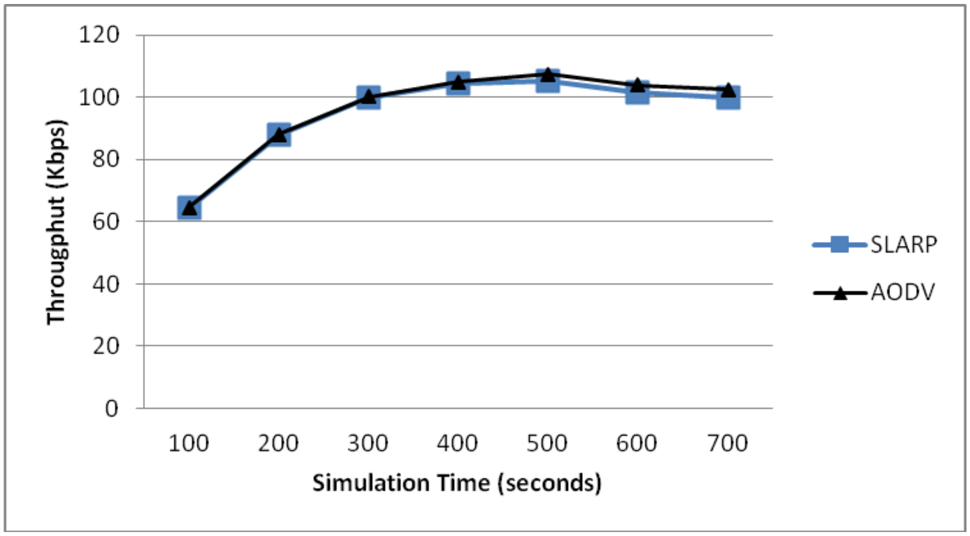

Figure 6.60: The throughput of five sources, each sends six packets per second.

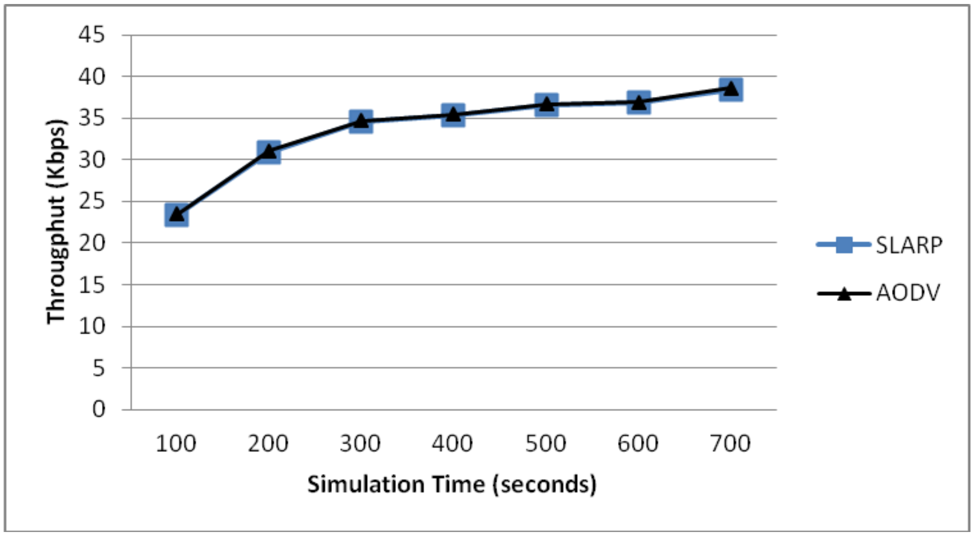

Figure 6.61: The throughput of ten sources, each sends one packet per second.

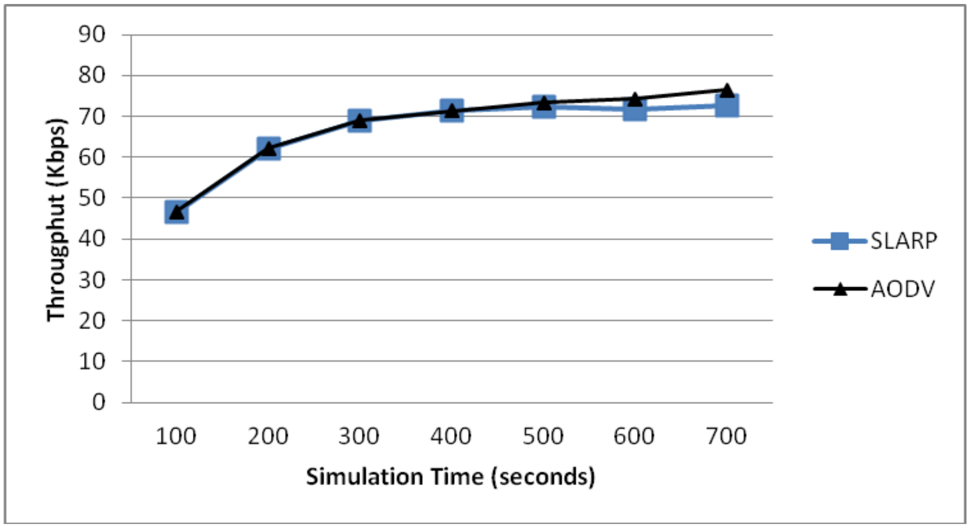

Figure 6.62: The throughput of ten sources, each sends two packets per second.

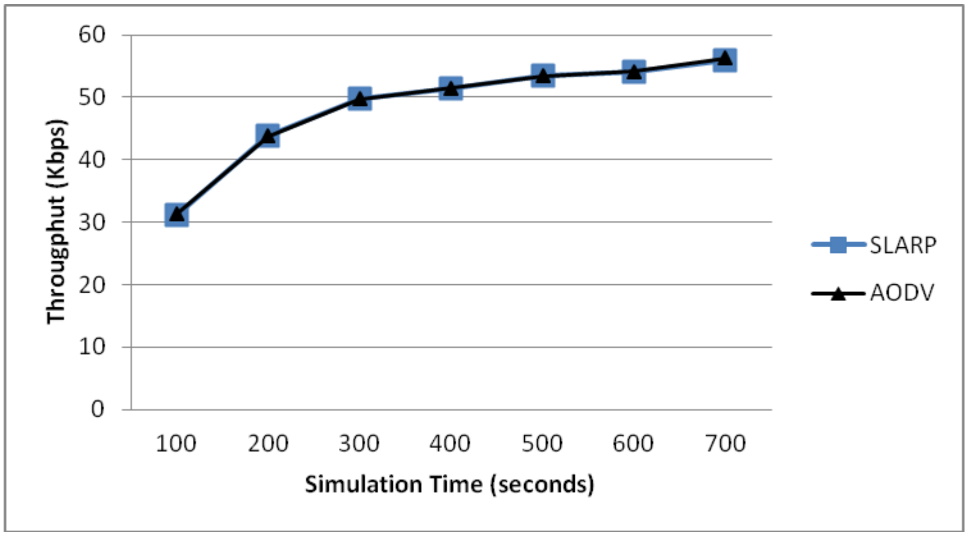

Figure 6.63: The throughput of fifteen sources, each sends one packet per second.

Figures 6.64~6.68 show that SLARP algorithm outperforms AODV in terms of throughput for different number of sources and different values for transmission rate under all simulation time values especially when simulation time values are more than 400 seconds, where the number of the dead nodes for SLARP algorithm is less than that in AODV algorithm, this is because these network scenarios are suffering from high level of congestion and excessive energy draining of nodes due to the high-load of the data traffic, where SLARP is working to avoid and reduce the congestion in the intermediate nodes by distributing the high-load. In figure 6.68, for example, SLARP outperforms AODV by 13.09, 19.47, 23.71, and 28.04 percent when the simulation time values are 400, 500, 600, and 700 secs, respectively.

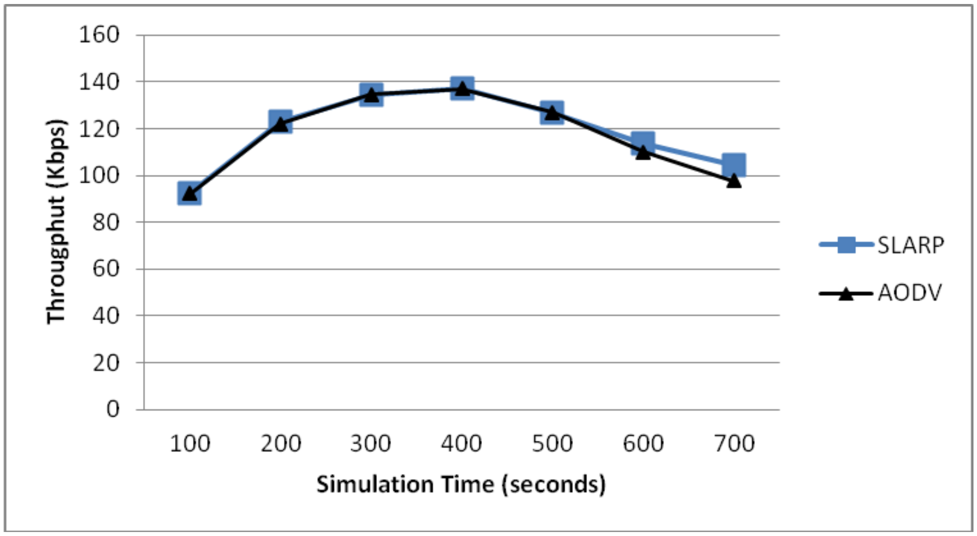

Figure 6.64: The throughput of ten sources, each sends four packets per second.

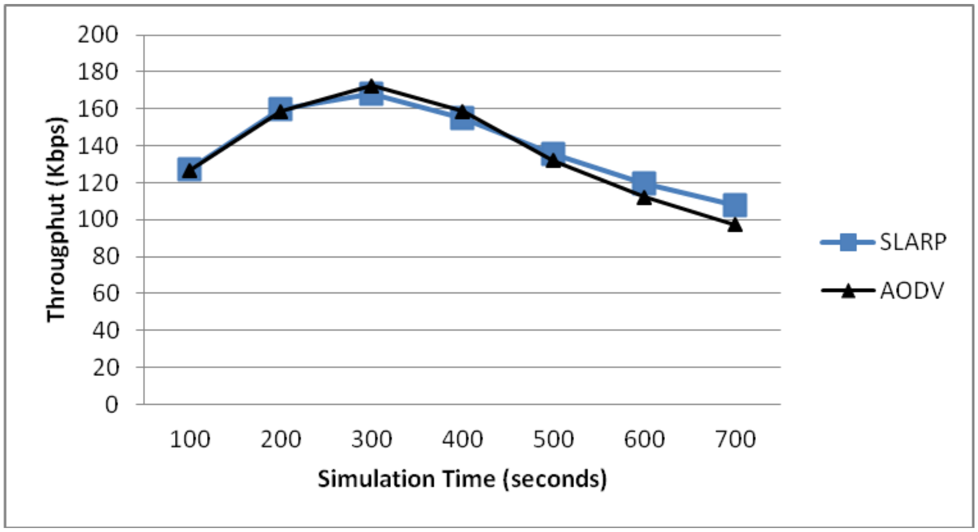

Figure 6.65: The throughput of ten sources, each sends six packets per second.

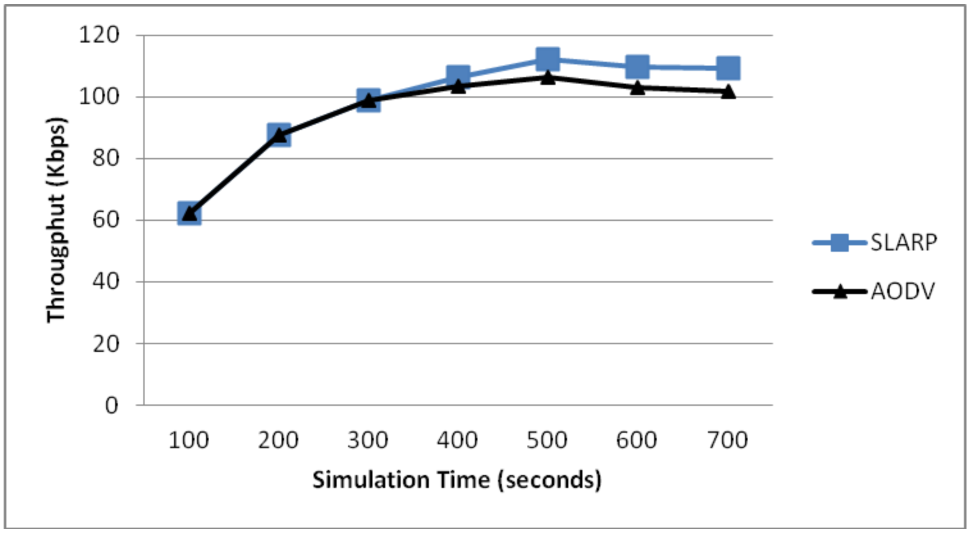

Figure 6.66: The throughput of fifteen sources, each sends two packets per second.

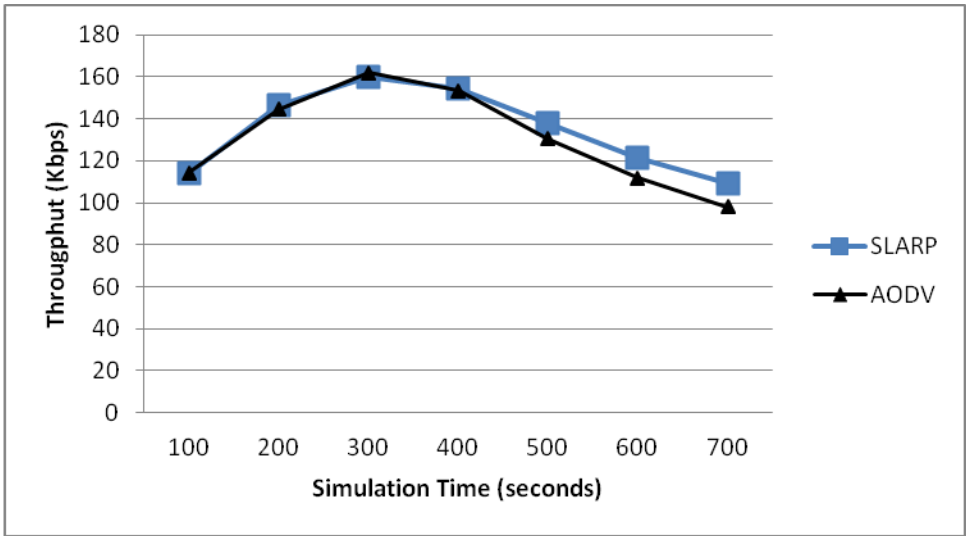

Figure 6.67: The throughput of fifteen sources, each sends four packets per second.

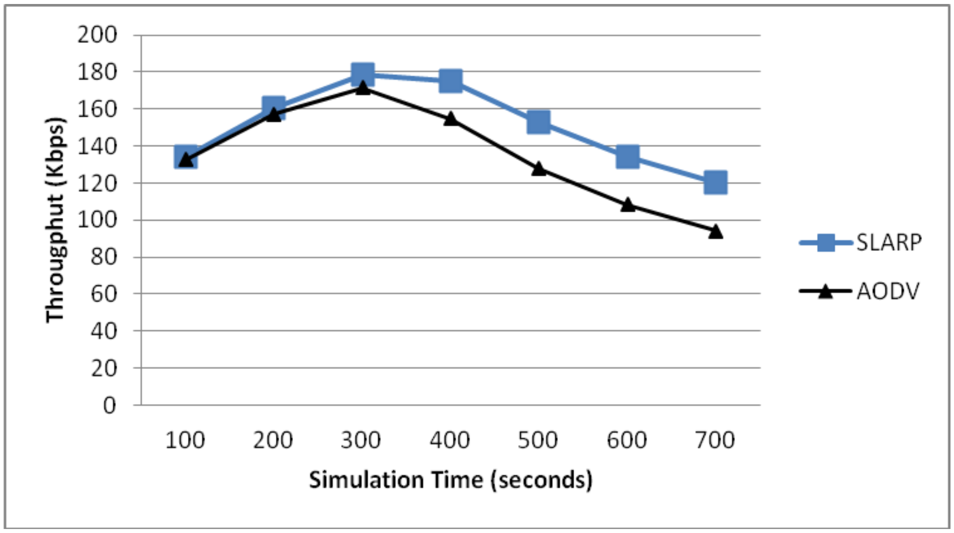

Figure 6.68: The throughput of fifteen sources, each sends six packets per second.

6- 7 Overhead

The network stands to lose many nodes by increasing the simulation time, the number of sources or the transmission rate, where nodes consume more energy to service the connections. SLARP maintains the nodes energy and the system lifetime as much as possible by distributing the data traffic loads according to residual energy amount and congestions level of the intermediate nodes. When an intermediate node is died, the source node needs to find a new route to the destination based on the route maintenance process, which results in an extra overhead. This justifies why the performance of SLARP is close to that of AODV in terms of overhead for light-load data traffic network scenarios at all simulation time values as shown in the figures 6.69~6.74 for the number of sources and transmission rates considered, and also justifies why the performance of SLARP is close to that of AODV at the beginning of the simulations for medium-load data traffic network scenarios, then and after a period of time the gap between them begins favor to SLARP as can be seen in the figures 6.75~6.76 for the number of sources and transmission rates considered. SLARP gives a wonderful superiority over AODV in terms of the overhead for heavy-load data traffic network scenarios as shown in figures 6.77~6.80 for the number of sources and transmission rates considered. In figure 6.78, for example, SLARP outperforms AODV by 8.1, 26.38, 37.56, 40.93, 43.35, and 44.63 percent when the simulation time values are 200, 300, 400, 500, 600, and 700 secs, respectively. This is due to the mechanism of SLARP in reducing the number of control packets that is required to maintenance the failures in routes by reducing the causes that lead to routes failures, such as nodes death situations.

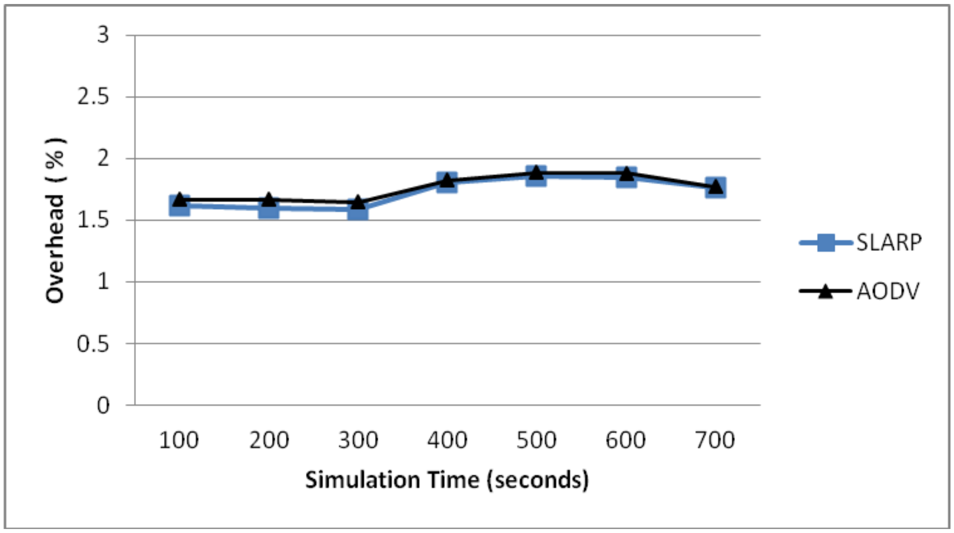

Figure 6.69: The overhead of five sources, each sends one packet per second.

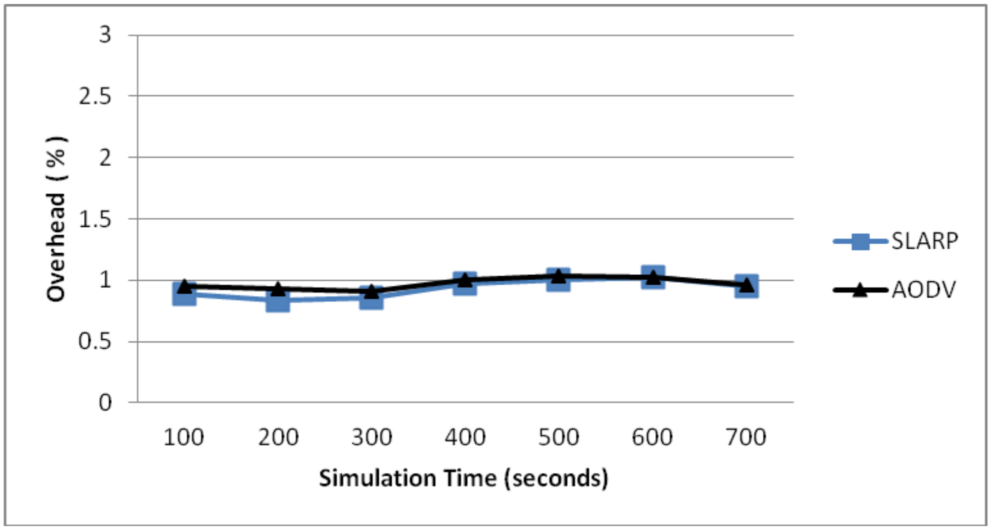

Figure 6.70: The overhead of five sources, each sends two packets per second.

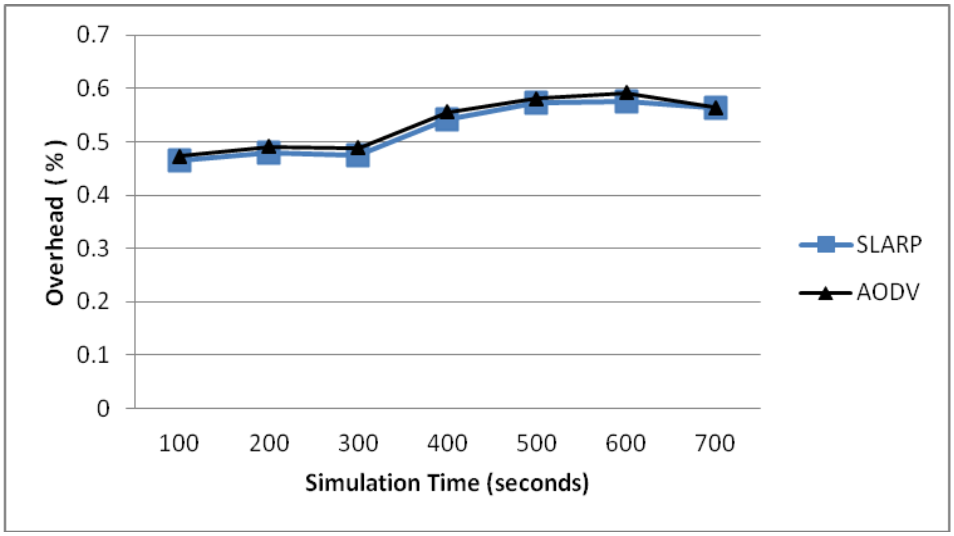

Figure 6.71: The overhead of five sources, each sends four packets per second.

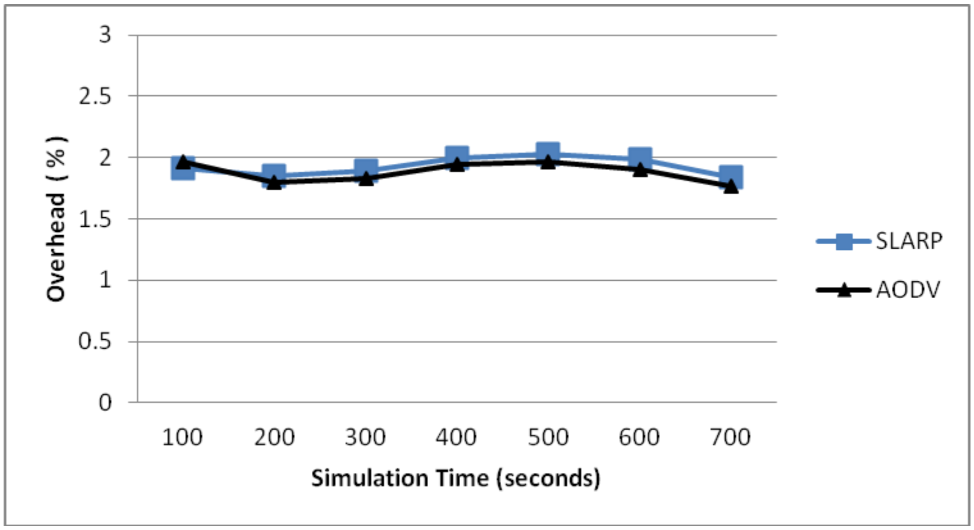

Figure 6.72: The overhead of ten sources, each sends one packet per second.

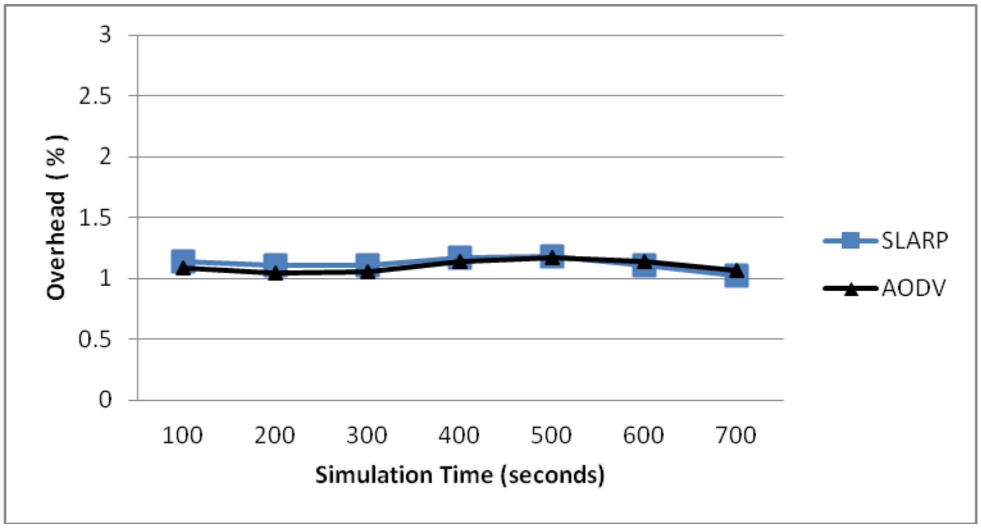

Figure 6.73: The overhead of ten sources, each sends two packets per second.

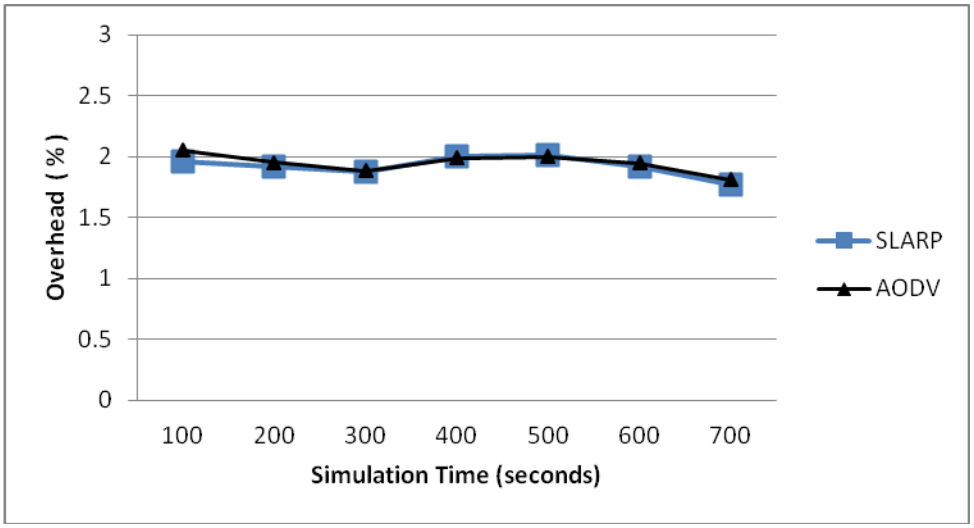

Figure 6.74: The overhead of fifteen sources, each sends one packet per second.

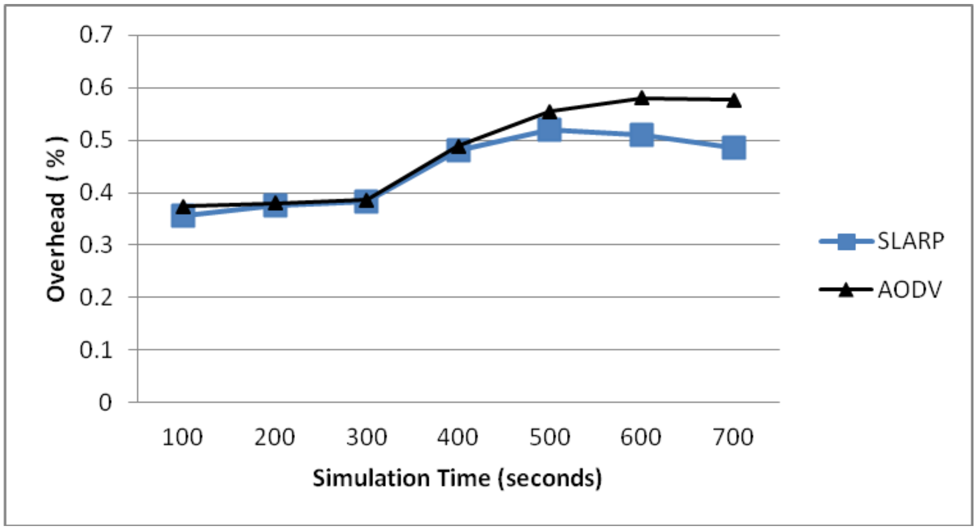

Figure 6.75: The overhead of five sources, each sends six packets per second.

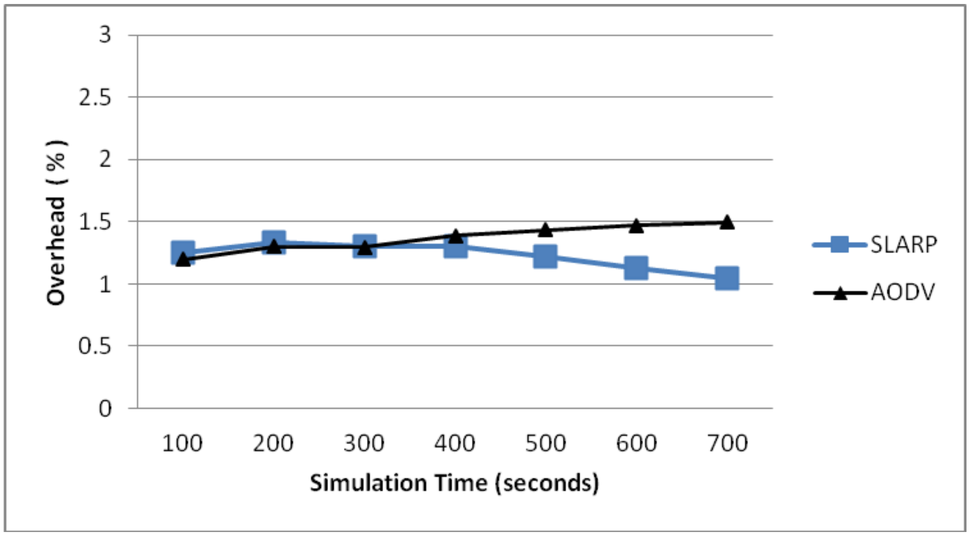

Figure 6.76: The overhead of fifteen sources, each sends two packets per second.

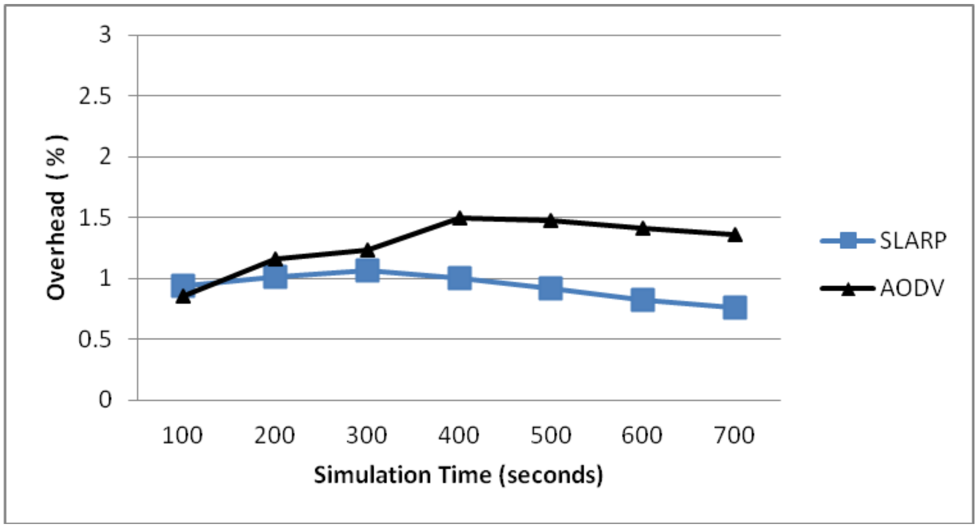

Figure 6.77: The overhead of ten sources, each sends four packets per second.

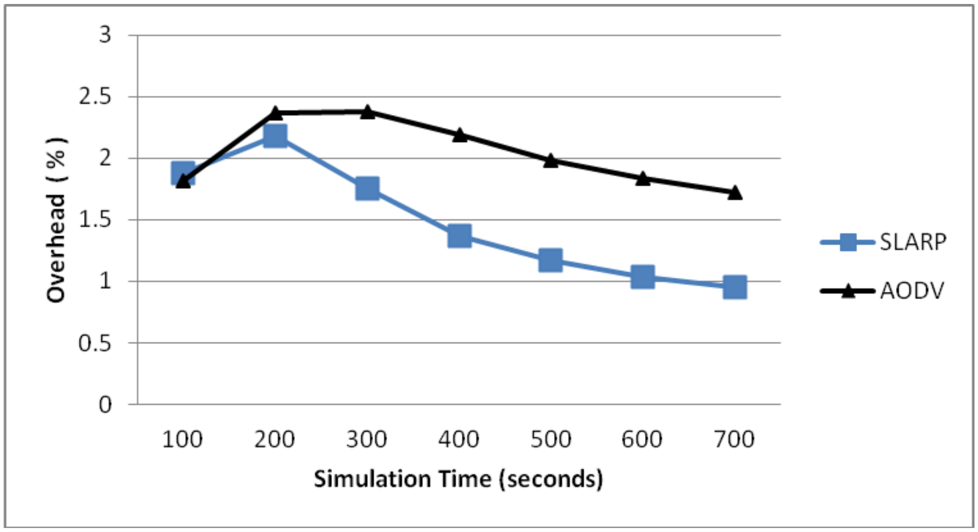

Figure 6.78: The overhead of ten sources, each sends six packets per second.

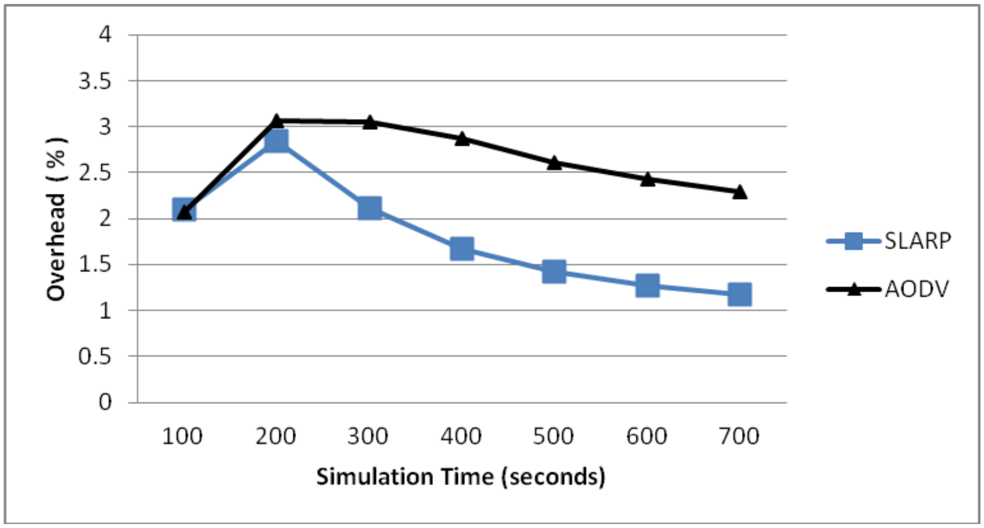

Figure 6.79: The overhead of fifteen sources, each sends four packets per second.

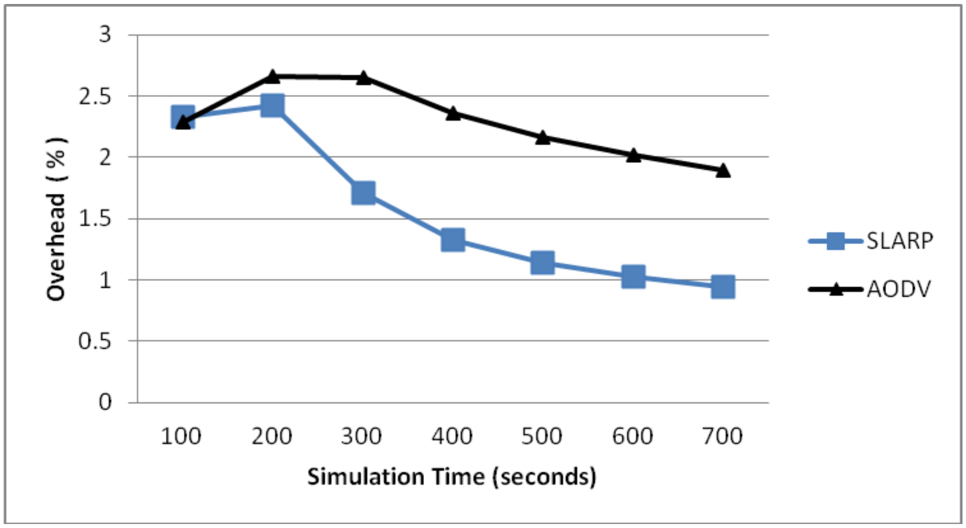

Figure 6.80: The overhead of fifteen sources, each sends six packets per second.

CHAPTER SEVEN: CONCLUSIONS AND FUTURE WORK

7-1 Conclusions

In this thesis, we have implemented a new Ad hoc routing protocol, which called SLARP, based on its respective underlying protocols AODV, in NS-2 simulation environment. Seven performance criteria: packets delivery ratio, average end-to-end delay, throughput, the overhead, percentage of consumed energy, the dead nodes ratio, and the average lifetime of dead nodes are used to evaluate the performance of SLARP and AODV. In order to get the accurate experimental results we have run each scenario ten times and we have used the four pause times (0, 100, 200, and 300 secs) in each experiment. And also, we varied the transmission rate for 1, 2, 4 and 6 packets per second, repeated for 5, 10, and 15 sources. Ninety-six scenarios have been created to evaluate the two protocols, each scenario is averaged over ten runs to find the (95%) confidence interval of each performance criteria. The collected performance criteria from the various scenarios are summarized below:

In terms of the dead node ratio, SLARP and AODV are fairly close to each other in the scenarios that have light data traffic because there are no dead nodes in such networks. While SLARP outperforms AODV in the scenarios that have a heavy data traffic. This improvement is achieved by using the load distribution mechanism in SLARP which results in reducing the congestion and energy drain that happened in the intermediate nodes.

In terms of the average lifetime of the dead nodes, SLARP and AODV are fairly close to each other in the scenarios that have light data traffic because there are no dead nodes in such networks. While SLARP outperforms AODV in the scenarios that have a heavy data traffic. This is because SLARP is working to distribute the load according to the amount of residual energy of the intermediate nodes, which results in extending the lifetime of the intermediate nodes as long as possible based on the threshold value that used.

In terms of the percentage of consumed energy, SLARP outperforms AODV in all simulated scenarios for all simulation time values. This is because SLARP is working to distribute the traffics according to the amount of residual energy of the intermediate nodes that have residual energy above the threshold value that used and selecting the latest busy path, thus no more power need to find new routes in case of node death.

SLARP and AODV are fairly close to each other in terms of packet delivery ratio in all simulation time values for most simulated network scenarios. However, in some cases such that of heavy data traffic, there is a non-influential decline of the packets delivery ratio in SLARP when the simulation time values are 500, 600 and 700 sec. This is because SLARP continues sending data for a time more than that of AODV due to the abundance in the lifetime and the energy of the intermediate nodes that provided by SLARP, which reflects the superiority of SLARP over AODV in terms of throughput.

In terms of the average end-to-end delay, SLARP outperforms AODV in all simulation time values for most simulated network scenarios. This improvement is due to load distribution mechanism of SLARP by avoiding the congested nodes and hence reducing the congestion as well, where the packets do not need to wait in the interface queue of the intermediate nodes for a long time. In some cases, particularly when the simulation time is greater than 400 seconds, AODV outperforms SLARP in terms of the average end-to-end delay, this is because SLARP continues sending data for a time more than AODV, and this can be seen by the superiority of SLARP in terms of throughput in these situations.

In terms of the throughput of light load scenarios, SLARP and AODV are fairly close to each other in all simulation time values. because these network scenarios are not suffering from a high level of congestion or excessive draining in nodes energy due to the light-load of the data traffic. While in the heavy load scenarios, SLARP outperforms AODV for all simulation time values in terms of the throughput, especially, when the simulation time values are more than 400 seconds, where the number of the dead nodes for SLARP algorithm is less than that for the AODV algorithm. Such network scenarios are suffering from a high level of congestion and excessive energy draining of nodes that leads to die many of the intermediate nodes. SLARP is working to avoid and reduce the congestion in the intermediate nodes by distributing the high-load.

In terms of the overhead, our proposed algorithm SLARP outperforms AODV in the scenarios that have a heavy data traffic but it is fairly close to AODV in the scenarios that have a light data traffic. This improvement in decrementing the overhead is achieved by reducing the congestion level in the intermediate nodes, thus increases the nodes availability in the system, which reduces the routes failures and routes maintenance.

7- 2 Future Work

Future research is needed to:

- Improved SLARP protocol needs to use a dynamic threshold value, and to use cumulative values of nodes residual energy and congestion level on the selected routes.

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المخلص

يعتبر عمر البطارية من المشكلات الرئيسية التي تواجهه الشبكات اللاسلكية والشبكات اللاسلكية المتحركة بصورة خاصة، حيث يتم تزويد العقد بالطاقة في الشبكات اللاسلكية المتحركة من خلال البطاريات وهي من المصادر المحدودة للطاقة، حيث يصعب اعادة شحنها في بعض الظروف كحالات الحرب او الكوارث الطبيعية، وهذا ما يشكل التحدي لعمر العقد في الشبكات اللاسلكية المتحركة مما يؤثر سلباً على عمر نظام الاتصال والشبكة بشكل عام. يعتبر مدى الازدحام في تدفق البيانات من الاسباب المهمة التي تؤدي إلى الاستهلاك المطرد لبطارية العقدة، كما يشكل عدم توزيع الأحمال على كافة العقد في الشبكة عاملا مهما في استنزاف الطاقة من بعض العقد في حين يبقى البعض الاخر في حالة جيدة من الطاقة، الأمر الذي يؤدي الى انهيار منظومة الاتصال في الشبكة بسبب موت بعض العقد وبالتالي توقف حركة مرور البيانات وعليه يجب العمل على محاولة اطالة عمر العقد وبالتالي إطالة عمر النظام بشكل عام.

تم في هذه الدراسة اقتراح خوارزمية لتجنب العقد المزدحمة والتي تعاني من نقص في الطاقة التشغيلية، ويتمثل مبدأ عمل الخوارزمية في أن العقدة المستقبلة تقوم باختيار المسار الأقل ازدحاما والأكثر طاقة متبقية من مجموعة من المسارات التي تربط عقدة المصدر بعقدة الهدف. تقوم الفكرة على ان كل عقدة وسطية تقوم بحساب قيمة الازدحام عندها وهذه القيمة تمثل عدد الحزم في قائمة الانتظار على منفذ الإرسال (Number of packets in its interface queue)، وكذلك تقوم العقدة الوسطية بحساب كمية الطاقة المتبقية لديها. فعندما ترغب عقدة المصدر بتمرير بيانات لعقدة الهدف ولا تملك مسار لهذه العقدة، تقوم بنشر رسالة طلب إنشاء مسار .(Route Request) تقوم العقد الوسطية بتمرير هذه الرسالة لعقدة الهدف مرفق معها الحسابات السابقة عندما تستلمها للمرة الأولى وتكون الطاقة المتبقية فيها أكبر من قيمة العتبة المحددة مسبقا. وعندما تستلم عقدة الهدف هذه الرسالة تقوم باختيار المسار الاقل ازدحاما والأكبر كمية من الطاقة المتبقية في العقد الوسطية ومن ثم الرد على رسالة طلب المسار من خلال إرسال رسالة جواب (Route Replay)وترسل هذه الرسالة للعقدة المصدر سالكة المسار العكسي للمسار الذي تم اختياره والذي سلكته رسالة طلب إنشاء المسار. وعندما تستلم عقدة المصدر رسالة الرد تبدأ فورا بعملية ارسال البيانات من خلال هذا المسار.

تم إجراء عدة تجارب محاكاة لقياس أداء الخوارزمية المقترحة ومن ثم مقارنة أدائها مع اداء برتوكول التوجيه عند الطلب (AODV) بمختلف ظروف المحاكاة من حيث زمن التوقف وعدد المصادر وحجم التدفق وزمن المحاكاة، أظهرت النتائج تحسينات ملموسة في إطالة عمر النظام والتقليل في عدد العقد المستنفذة طاقتها مقارنة مع بروتوكول التوجيه عند الطلب.(AODV)

Appendix A

Number of Sources		5															
Transmission Rate (Packets/sec)		1				2				4				6			
protocols		SLARP		AODV		SLARP		AODV		SLARP		AODV		SLARP		AODV	
Confidence Interval		Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value	Low Value	High Value
		Average Dead Nodes Ratio															
Simulation Time	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	400	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	500	0	0	0	0	0	0	0	0	0	0	0	0	1.731932417	3.768067583	4.146627948	7.653372052

100	**Average Lifetime of Dead Nodes**	**700**	**600**
0		0	0
0		0	0
0		0	0
0		0	0
0		0	0
0		0	0
0		0	0
0		0	0
0		1.166601234	0.015136321
0		3.033398766	0.484863679
0		4.784280042	0.607100284
0		12.31571996	2.092899716
0		24.60558191	12.70195713
0		30.09441809	19.49804287
		5.385471178	6.521572158
0		35.16452882	20.97842784