A Comparative Study of Reactive Routing Protocols for Industrial Wireless Sensor Networks

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Abstract. There have been a continuously growing demand for the efficient and infrastructure less Industrial Automation Systems (IAS), to fulfill the rapid changes in real world requirements. During the past decade, wireless sensor networks have been evolved as a powerful tool for the industrial process monitoring and distributed control. In the Industrial wireless control system, sensor nodes are deployed over an area, to monitor physical and or environmental conditions such as temperature, pressure, vibration, motion, sound, humidity etc. For the reliable control function, measured parameters should be delivered to the actuators in real time and reliable manner. Thus, considering the energy constraints of sensor nodes various reactive routing protocols are being used for the real time and reliable message delivery. The aim of this paper is to present a comparative study of existing reactive routing protocols in Industrial Wireless Sensor Networks (IWSNs).

Keywords: AODV, DSR, DYMO, IWSNs, LAR, Reactive routing.

1 Introduction

Today's fast growing competitive industries face growing demand to upgrade their processes for industry automation with improved productivity, efficiency and Quality at low cost [1][15]. Traditionally, IAS are realized through wired communication. However, the wired communication based automation systems require expensive communication cables, to be installed and maintained regularly. Therefore there is a vital need for cost-effective communication systems. Recent developments in the field of Micro Electro Mechanical Systems (MEMS) and WSNs made low cost embedded IAS feasible [2] [3] [15]. The sensor nodes are installed with industrial equipments to monitor various parameters such as temperature, pressure, vibration, power, humidity etc. The sink node (also a sensor node) is installed at remote center for gathering and performing control actions. The nodes work together to analyze and enable control action for maintain quality and productivity. It also warns for repair or replacement of

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the equipment to meet safety and security norms. A set of sensor node, shares wireless medium, communicate with each other without any predefined infrastructure and central controller. The participating nodes which are not in communication range may communicate in multi hop manner. They follow a well defined hopping sequence in order to comply with the routing policy and to cope well with network dynamics. Hence, the routing protocols play a vital role to select a suitable optimum route, and transmit data on selected path. The reliability of the routing protocol has a direct influence on factors such as network dynamics, coverage, prolonging of the network life time, Packet Reception Rate (PRR), Quality of Service (QoS), fault tolerance and fairness [1][5][15]. Since energy is a main constraint of wireless sensor node, the reactive routing protocols are best suited for reliable data delivery in WSNs. Thus we have chosen and considered reactive routing protocols for the comparative study.

This paper presents the comparative study of performance of well established reactive routing protocols such as AODV, DSR, DYMO and LAR in industrial prospects using QualNet simulator. The organization of the paper is as follows: Section 2 describes routing protocols in IWSNs for real time reliable message delivery. Section 3 describes the simulation scenario, Section 4 presents a discussion over simulation results and finally, Section 5 concludes the paper with future research directions.

2 Routing in Industrial Wireless Sensor Networks

The information routing is most challenging task in the industrial wireless environment due to the inherent characteristics of the wireless sensor networks as dense deployment, nodes mobility and energy constraints. The major issues that need to be addressed are maximizing network lifetime, minimizing latency, resource awareness, topological changes, location awareness, scalability, reliability and real time data delivery [6]. As the sensor networks are a type of Mobile Ad-hoc Networks (MANET), same routing protocols can also be used for IWSNs [4].

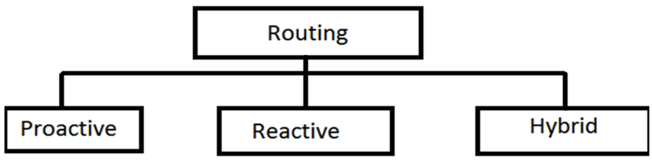

Fig. 1. Routing protocol classification

As shown in figure 1, the routing protocols may be classified as proactive reactive and hybrid. Proactive routing protocol is also known as table driven routing protocol [7]. Each node is required to store routing information in the network. The network status is updated either periodically or when the network topology changes, results in low latency, thereby suitable for real-time traffic, but the bandwidth gets wasted due to periodic updates. Moreover, as these protocols are not energy efficient, its reliability is questionable as for as WSN is concerned. Example protocols are Ballman ford Routing Protocol, Destination Sequenced Distance Vector Routing (DSDV), Optimized Link State Routing Protocol (OLSR) and Source Tree Adaptive Routing (STAR).

Reactive routing protocol discovers the route, when needed, hence called “On Demand routing protocol”. The process of route discovery is done by flooding the Route REQuest (RREQ) packets throughout the network. Reactive routing protocol always uses the current status of network hence the traffic is generated in bursty manner, which may create congestion during high activities. The significant delay may occur as a result of route discovery. But it saves energy and bandwidth during inactivity period. It’s good for low traffic [7]. Examples Protocols are Ad-Hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), Dynamic MANET On-demand (DYMO) and Location Aided Routing (LAR).

The Hybrid routing protocol is the mixed structure of proactive and reactive routing protocol. The best features of proactive routing protocol and reactive routing protocols as low latency and less bandwidth requirement respectively are being incorporated in hybrid routing as attempts to strike balance between the two. The example protocols are, Zone Routing Protocol (ZRP), Core-Extraction Distributed Ad-hoc Routing (CEDAR).

As for as real time reliable delivery is concern the reactive routing protocols may be used because it saves bandwidth and requires fewer resources which may lead it, to be used for industries. The energy saving in inactive period improves reliability and low traffic requirement makes reactive routing protocol suitable for IWSNs.

2.1 Ad-Hoc On Demand Routing Protocol

The Ad hoc On-Demand Distance Vector (AODV) is a reactive routing protocol. On demand basis it establishes a route to the destination hence it is called as AODV. It enables dynamic, self-starting, multihop routing between participating nodes wishing to establish and maintain an ad hoc network. AODV allows obtaining routes quickly for new destinations, and does not require nodes to maintain routes to destinations that are not in active communication [8] [9]. AODV allows mobile nodes to respond to link breakages and changes in network topology in a timely manner. The operation of AODV is loop-free, and by avoiding the Bellman-Ford "counting to infinity" problem offers quick convergence when the ad hoc network topology changes. When a node needs to know a route to a specific destination it creates a Route Request, forward to sink node through intermediate nodes. Intermediate node stores a reverse route. When the request reaches a sink node, creates a reply which contains the number of hops that are requiring reaching the destination [9]. All intermediate node, stores the forward route in their routing table. This route created from each node from source to destination is a hop-by-hop state and not the entire route as in source routing.

2.2 Dynamic Source Routing Protocol

The Dynamic Source Routing protocol (DSR) is routing protocol designed for multi-hop wireless networks where nodes are mobile. DSR allows the network to be completely self-organizing and self-configuring [10]. It uses the route discovery cycle for route discovery and uses the route maintenance cycle to maintain the active routes. These cycles work together, discover and maintain the route in reactive manner, create the routing packet overhead for searching the routes dynamically. It prolongs the network life time, load balance, by providing flexibility to sender to choose and control route among selected routes to destination [11]. When a node S wants to send a packet to node D, but does not know a route to D, node S initiates a route discovery. Source node S floods RREQ packet. The RREQ consist of sender address, destination address and unique request id determined by the sender. Each node appends its own identifier when it forwards the RREQ packet. The Route REPly (RREP) can be send by reversing the RREQ only if links are guaranteed to be bidirectional. If unidirectional links are allowed, then RREP may need a route discovery for S from node D. Route discovery is not needed if D already knows a route to node S. If a route discovery is initiated by D for a route to S then the RREP is piggybacked on the RREQ from D. DSR protocol provides loop- free routing, rapid recovery when routes in the network change. The DSR protocol is designed mainly for mobile ad hoc small networks (Approx. two hundred nodes) with high mobility [10].

2.3 Dynamic MANET On-Demand

The DYnamic MANET On-demand (DYMO) routing protocol is designed for mobile nodes, intended to work in wireless multihop networks [12]. It dynamically changes the network topology and on demand it determines unicast routes between nodes. The route discovery and route management are the two basic operations of the DYMO routing protocol. In route discovery phase the Source node initiates dissemination of a RREQ packet throughout the network to find the destination node. In the dissemination process, each intermediate node records a route to the source node. As the destination node receives the RREQ packet, responds with a RREP packet. RREP packet is a unicast massage intended for source node. The intermediate node that receives the RREP message records the route for destination node. As the source node receives the RREP, the full duplex path between source and destination has been established. At the time of network changes, nodes maintain their routes and monitor their links, if communication between source destinations breaks, the source node is notified by Route ERRor (RERR) packet. Hence the source node again initiates the route discovery if it still has packets to be delivered.

DYMO routing protocol is basically designed for small, medium, and large population mobile ad hoc networks [12], it can handle large mobility ranges, various traffic patterns, but it best suited to lightly loaded networks. It requires small memory to store active destination only instead of storing all destination routing information. Further a Sequence Number (SeqNum) is maintained by each node. This sequence number insures the freshness of related routing information for loop-free routes.

2.4 Location Aided Routing

Location aided routing (LAR) is a demand based routing technique. It utilizes the location information to optimize the routing overhead by flooding route request packets in selected area. When a source node requires a path to destination node, source broadcast RREQ Packet to all its neighbor nodes. The neighbor node that receives RREQ packet compares its identifier with desired destination identifier. If the match found the node knows that request is for a route to itself, forwards the message otherwise node broadcasts the request to its neighbors to avoid redundant transmission. As the RREQ packet being forwarded the path following information is incorporated in the RREQ. As the destination node receives RREQ packet, reply to sender through RREP packet. The RREP packet follows the path mentioned in the RREQ packet received by destination node. To avoid the loss of route discovery the sender set a timeout at the RREQ transmission, if the RREP is not received before timeout, a new RREQ packet is initiated with different sequence number. The sequence number are useful in duplicate packet receptions at same route. During the data transmission, when a packet moving towards destination did not get the path towards the destination sends RERR packet to source node, to discover the new route.

3 Simulation Setup

The performance parameters were observed and analyzed using simulation model based on QualNet [13]. QualNet is discrete event network evaluation simulator software, developed by Scalable Networks and is a commercialized version of GloMoSim. It analyzes the performance of wired, wireless and hybrid network, supports thousands of nodes for simulation and works with 32 and 64 bit operating systems like UNIX, Linux and MacOS.

Reactive routing protocols as AODV, DSR, DYMO and LAR were considered for simulation using QualNet 5.0.2, considering the varying node mobility while maintaining the constant traffic load using 4 CBR, with different node density as 25, 50, 75 and 100 on a 500x500 meter^2 scenario as given bellow.

Table 1. Scenario Parameters

Simulation Parameters	**Value**
Routing Protocols	AODV, DSR, DYMO, LAR
Scenario Dimensions (meters)	500x500
Simulation time (seconds)	100
No of Nodes	25,50,75,100
Mobility Model	None, Random Waypoint
Path Loss Model	Two Ray
Shadowing Mode	Constant
Pause Time (seconds)	0
Minimum speed (mps)	0
Maximum speed (mps)	1,2,3,4,5
No of CBR Application	04
Packet to be send	∞
Inter Packet Interval(second)	1
Start Time (second)	0
Packet size (bytes)	512

The above said routing protocols were configured with the matrix like Packet Reception Rate (PRR), throughput, jitter and end to end delay with respect to mobility. To support walking speed for maintaining network connectivity as handheld device changes its position in industrial environment, 1 meter per second (mps) as minimum and 5 mps as maximum mobility is considered.

4 Results and Discussion

4.1 Packet Reception Rate (PRR)

The Packet Reception Rate (PRR) represents how many percentages of packets are successfully delivered at destination node [14]. For reliability point of view a larger value of PRR is required. Here we have considered mobility, which may results deteriorate the PRR. Figure 2, 3, 4 and 5 represents the performance of PRR-Vs mobility with AODV, DSR, DYMO and LAR routing respectively. The evidence shows that more or less selected routing protocol performs equally well with different node density and mobility but AODV routing protocol performs exceptionally well, remains constant as node density and mobility increases.

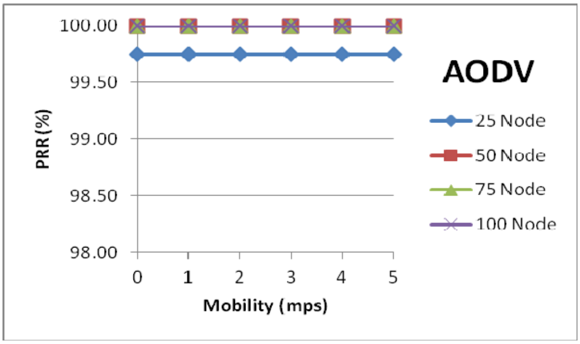

Fig. 2. PRR Vs Mobility for AODV Routing Protocol with varying Node Density

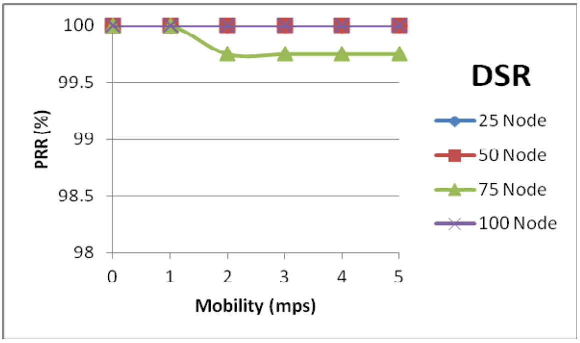

Fig. 3. PRR Vs Mobility for DSR Routing Protocol with varying Node Density

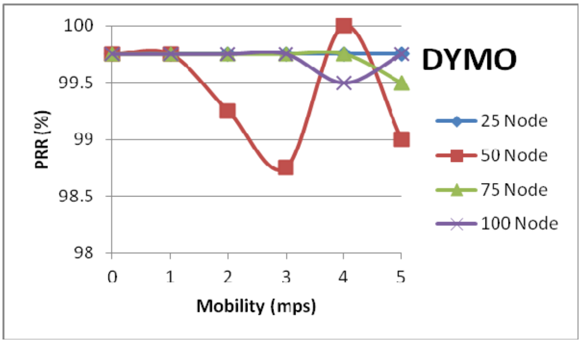

Fig. 4. PRR Vs Mobility for DYMO Routing Protocol with varying Node Density

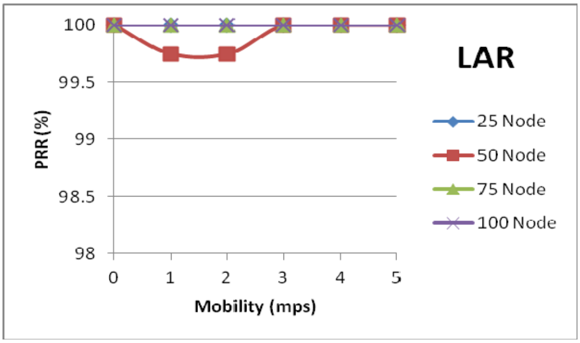

Fig. 5. PRR Vs Mobility for LAR routing protocol with varying node density

4.2 Throughput

Throughput of a network is a measure of the average rate of successful message delivered over a communication channels. In WSNs scenario the reliability depends upon the throughput also. A higher value of throughput is required for better network reliability and capability. Figure 6, 7, 8 and 9 shows the effect of mobility on the

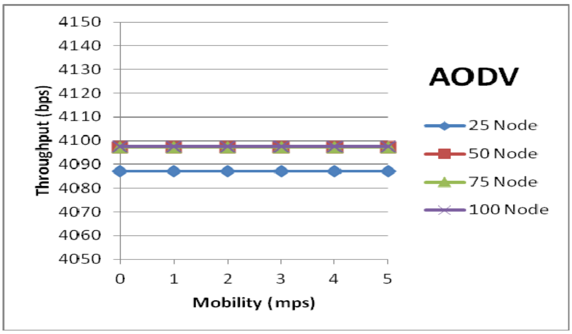

Fig. 6. Throughput Vs Mobility of AODV routing protocol with varying node density

varying network density with AODV, DSR, DYMO and LAR routing respectively. The result shows that with the selected range of mobility AODV, DSR and LAR performs better than DYMO routing but the performance of LAR is outstanding. It provides maximum throughput value.

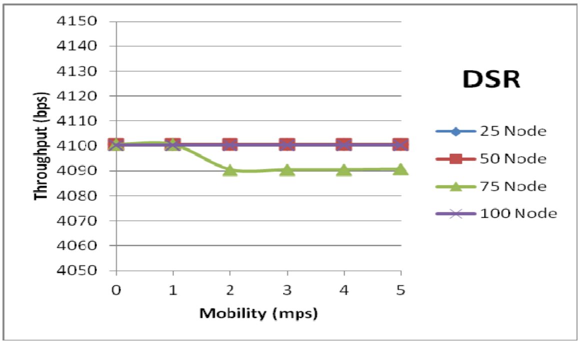

Fig. 7. Throughput Vs Mobility of DSR routing protocol with varying node density

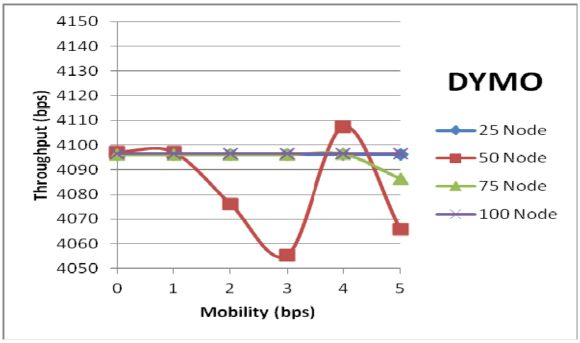

Fig. 8. Throughput Vs Mobility of DYMO routing protocol with varying node density

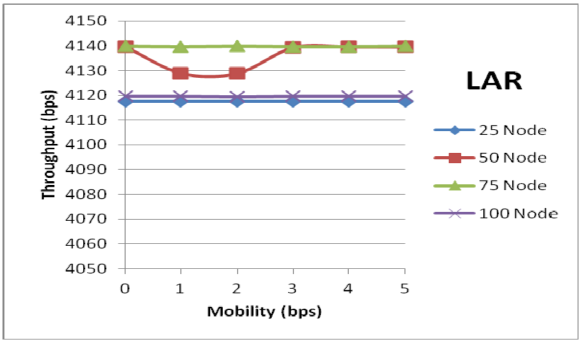

Fig. 9. Throughput Vs Mobility of LAR routing protocol with varying node density

4.3 End to End Delay

The end to end delay refers to the time taken by information to move from source node to destination node. It includes time taken by information at transmitter and receiver end as well as at the channel for propagation. The network performance for dead line delivery of data end to end delay is considered [14]. Results shown in figure 10-13

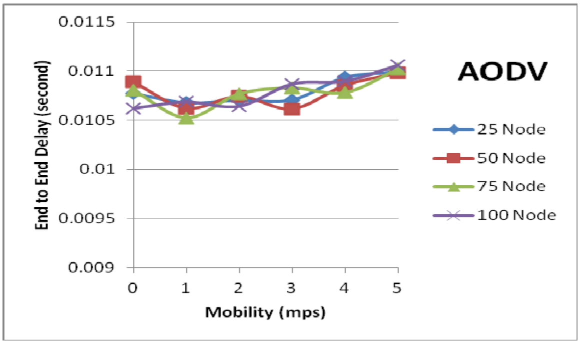

Fig. 10. End to end delay Vs Mobility for AODV Routing with varying node density

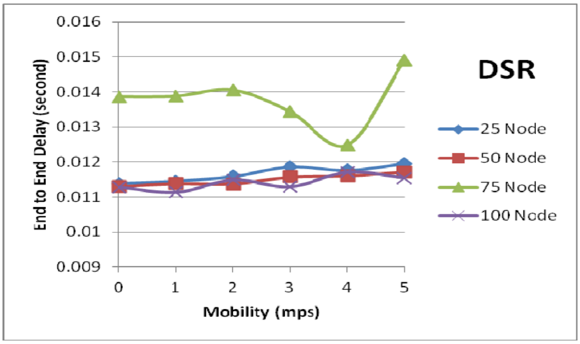

Fig. 11. End to end delay Vs Mobility for DSR Routing with varying node density

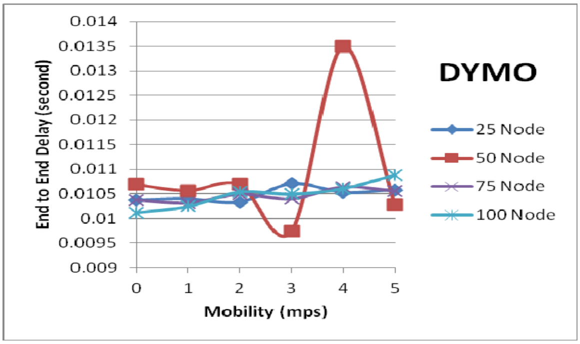

Fig. 12. End to end delay Vs Mobility for DYMO Routing with varying node density

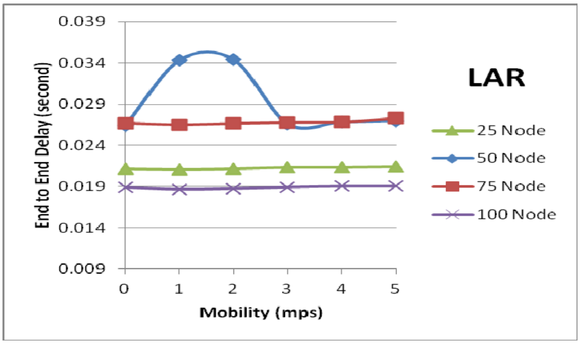

Fig. 13. End to end delay Vs Mobility for LAR Routing with varying node density

shows that DYMO routing protocol performs better than other routing protocols because it requires minimum end to end delay but AODV routing protocol requires slightly more delay for smooth performance which increases slightly with mobility.

4.4 Jitter

Jitter is inter packet delay variation which occurs in packet switch networks. It is variation in latency, effects real time applications, its significant value affect network performance also. Figure 14 to 17 represents jitter variation with mobility in AODV, DSR, DYMO and LAR routing protocols with increasing node density of network. Result show that as per property, AODV and DYMO performs well and jitter increases with mobility. Out of AODV and DYMO, AODV shows slightly more jitter than DYMO.

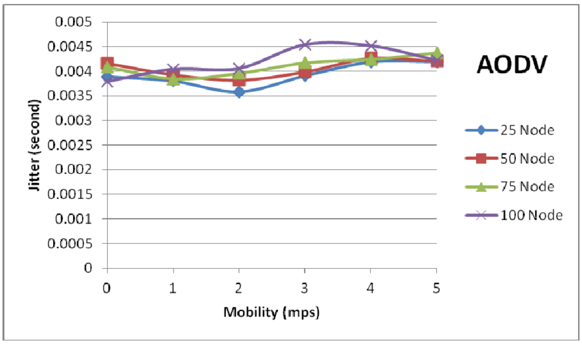

Fig. 14. Jitter Vs Mobility for AODV Routing with varying node density

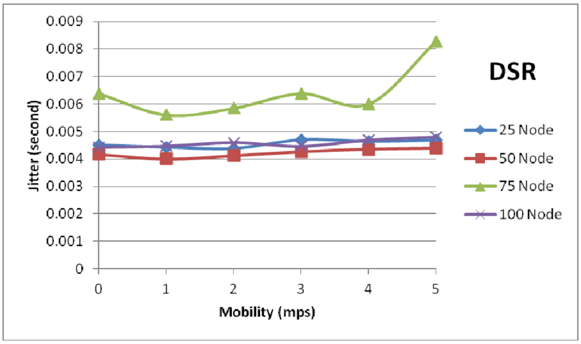

Fig. 15. Jitter Vs Mobility for DSR Routing with varying node density

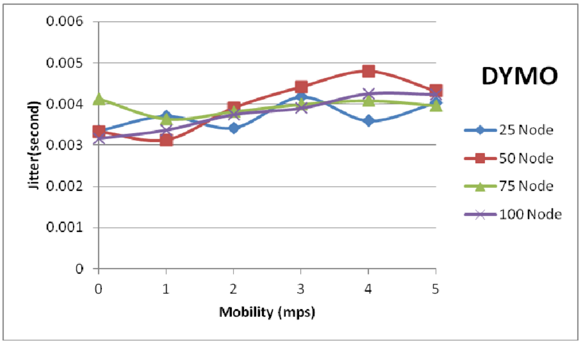

Fig. 16. Jitter Vs Mobility for DYMO Routing with varying node density

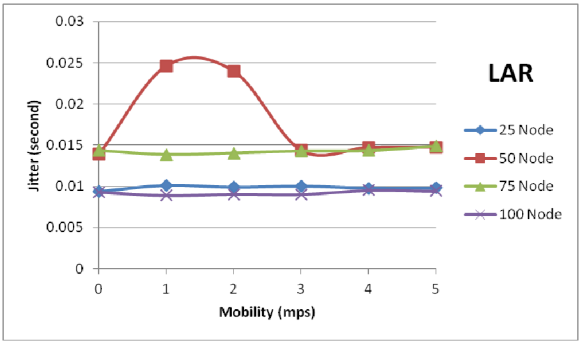

Fig. 17. Jitter Vs Mobility for LAR Routing with varying node density

5 Conclusion

Result shows that as for as PRR and end to end delay performance is concern the AODV routing protocol performs best among other routing protocols. As for as throughput is concern the LAR performs best but for the jitter point of view DYMO routing protocol may perform best. In nut shell tradeoff is required between various considered performance parameters. AODV may be considered best as for as PRR, end to end delay and jitter is concerned. From throughput point of view, LAR routing may perform well.

The reliable packet delivery always depends upon PRR and throughput, real time packet delivery depends upon end to end delay. For real time streaming function end to end delay and jitter play an important role. Real time in Industry automation and control shows that measured parameters and control information should arrive at destination node in acceptable delay limit. The late delivery of information may degrade or damage the performance and functioning. So depending upon the application requirement and criticality the routing protocol may be selected.

Future work will include the gradient setup considering the various metric for each link used to compute the path according to some objective function such as throughput, latency etc that may improve network reliability for real time data delivery in IWSNs.

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