A Review of Various Swarm Intelligence Based Routing Protocols for Iot

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Abstract*:* The paper provides insight into various swarm intelligence based routing protocols for Internet of Things (IoT), which are currently available for the Mobile Ad-hoc networks (MANETs) and wireless sensor networks (WSNs). There are several issues which are limiting the growth of Internet of Things. These include the reliability, link failures, routing, heterogeneity etc. The MANETs and WSNs routing issues impose almost same requirements for IoT routing mechanism. The recent work of the worldwide researchers is focused on this area. protocols are based on the principles of swarm intelligence. The swarm intelligence is applied to achieve the optimality and the efficiency in solving the complex, multi-hop and dynamic requirements of the wireless networks. The application of the ACO technique tries to provide answers to many routing issues. Using the swarm intelligence and ant colony optimization principles, it has been seen that, the protocols' efficiency definitely increases and also provides more scope for the development of more robust, reliable and efficient routing protocols for the IoT. As the various standard protocols available for MANETs and WSNs are not reliable enough, the paper finds the need of some efficient routing algorithms for IoT.

Keywords: MANET, WSN, Swarm Intelligence, IoT, Routing.

INTRODUCTION

Mobile Ad hoc Network (MANET)

The Mobile Ad hoc Network forms a temporary network with a collection of wireless moving devices without the centralized control and/or support services. In these types of networks, the devices create the dynamic topology environment wherein these can enter and exit frequently. There is no fixed infrastructure for the configuration or the reconfiguration of the network [1]. The MANETs are mostly used in the meetings, military communications, disaster recovery situations etc. The participating nodes or the devices face the challenge of limited communication range. Every device moves on

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independently frequently changing its links to other devices. Each device acts as the router to forward the traffic from the source to the sink.

The multicast routing protocols are required. The various challenges faced in such networks are frequently changing topology, low bandwidth issues, less battery life etc. The protocols which offer the advantages such as high throughput, better power utilization, adaptable to dynamic topology, less number of payload delays etc. are mainly required and much in demand. These factors if fulfilled may provide the Quality of Service (QoS) [2, 43].

Wireless Sensor Network (WSN)

Wireless Sensor Network is the collection of various spatially distributed autonomous nodes forming wireless network topology, basically using the sensors and actuators to predict the surrounding environment. The environmental conditions may include temperature, pressure, sound, vibration etc.

Most of the nodes in a WSN are stationary as compared to MANETs. Also, MANET offers the distributed computing whereas WSN is for the information gathering purposes. WSNs offer centralized control with low data rate. But both are distributed wireless networks involving multi hop routing, low battery nodes and which is self-organizing in nature [2]. The data cannot be sent directly from the source to the sink. The multi hop mesh topology requirement lays emphasis on the fact that it has to travel through the in-between sensor nodes to reach the desired destination. The protocols can be categorized in the following ways:

- Routing based on the network structure - It includes the flat based routing in which every node participates in the network and plays the same prescribed role. In horizontal routing, only high energy nodes are selected for the route formation. And in the Location based routing, the sensor nodes are identified using signal strength parameter and are controlled through Global Positioning System (GPS).
- Routing based on the protocol operation- In Multipath selection routing, the route is chosen among the various available paths, compromising on energy resource. In query based routing, the communication between the sender and the receiver is through queries. In Negotiation based routing, the negotiation is done to eliminate the high level of data redundancy.
- Routing based on how the source finds out the destination- The Proactive type of protocols; the route is decided before the need arises. Whereas the Reactive type of protocols, decide the route only when such demand arises in the network. In the Hybrid type of protocols, these offer the mix of proactive and reactive protocol categories.

- Routing based on the communication initiator- The request to send or receive the data may arise from the source or the sink, deciding on the initiator of communication category.
- Routing based on the criteria of selecting the neighboring node- In the Content based routing, the content or the kind of the data is more focused upon for the route selection. In the Probabilistic routing type of protocols, there is random selection of the neighboring nodes for data transmission. In the Broadcast routing methods, each node re-broadcasts the message and if undelivered, it is dropped.

Swarm Intelligence

It originated from the field of computational intelligence. This approach has now been widely used to solve complex optimization problems. The social insect colonies have the properties like collective behavior and the decentralized control [3]. These principles can be applied in the distributed, parallel and dynamic systems. Therefore, a swarm in networks can be defined as the collection of moving nodes which are participating in the collective manner for solving complex problems. These swarms are natural and form the basis for the logical transmission of data in the complex computing environments. Instead of having centralized control for the group, the control is localized.

Ant Colony Optimization (ACO): Marco Dorigo introduced the principle of ant colonies to answer the various combinatorial optimization problems and termed as Ant Colony Optimization [4, 5]. The ACO technique effectively exploits the swarm intelligence principles. It says that individual ants may not be smart enough but their colonies are. An ant colony can easily search food, find optimal routes and make plans. Each ant in the colony while travelling leaves a pheromone which is followed by other ants, also leaving their pheromones. Gradually the pheromone goes so strong that the shortest path is found by the ants. Based on these ant colonies, the Ant Colony Optimization (ACO) technique has been developed, consisting of artificial agents for solving the complex problems for providing shortest paths with minimum costs on a weighted graph.

This comparative analysis takes into consideration the various swarm intelligence [6] based routing algorithms applied in the MANETs or WSNs [7]. For making efficient and optimum utilization of the constrained resources of the wireless networks, the ACO approach takes the advantage of the swarm intelligence [8]. As route optimization is most important in the wireless networks for providing QoS, the swarm intelligence principles are continuously being implemented.

Internet of Things (IoT)

The term "Internet of Things" was introduced by Kevin Ashton in 1999. There is continuous evolution of Internet. The internet is on the verge of

expansion. Every object is getting connected and they will have their own unique identity [9].

The current static nature of internet will be transformed into the very dynamic Future Internet i.e. Internet of Things. As the humans are related with the internet same is that the devices are related with internet of things. The devices are dependent on the humans for generating all the information. The humans are lacking the resources such as time, accuracy and attention. There is a great requirement of having machines behaving independently [10, 11]. It will greatly reduce the waste, cost and loss of resources. The things will know where to act and what to act for.

The main aim of the IoT is to increase the persuasiveness and the ubiquity of the current internet and thus there would be integration of anything, anytime, anywhere and by anybody. Currently, we are in the first phase of IoT development. There are several issues which are limiting its growth [12]. Lot of research has been continuing in the concerned area to provide the best of connectivity and efficient usage of resources of the network and the external networks. Several protocols have been designed and developed for optimum path selection. The path selection has been done on the basis of residual energy of nodes, number of forwarding nodes in the path, the occurrence delay metric etc. As the internet is growing at a much faster rate [13], the continuously increasing number of interconnected devices causes scalability problems. There will be the need of flexible infrastructure [14] to deal with the various issues arising in the dynamic environment. The requirements of the IoT routing and communication protocols are similar to as that of the routing protocols for the Mobile Ad hoc Networks (MANETs) and the Wireless Sensor Networks (WSNs). IoT can be considered as the extension of integration of both the MANETs and the WSNs [15, 16]. Several questions need to be answered such as:

- How to select the optimum path for data forwarding in multi-hop mesh networks?
- How to use the resources in the efficient manner?
- How to improve the reliability and scalability to the network?
- How to deal with the payload delivery issues in the network with respect to heterogeneity of the networks?
- How to increase the lifetime of the network?

LITERATURE REVIEW

IoT is still in its infant stage [44] where several issues need to be addressed. Till now, various routing algorithms have been proposed for MANETs as well as for WSNs. These algorithms belong to the category proactive, reactive or hybrid. It is expected that these algorithms can be used as standards for the

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upcoming IoT. More efficient protocols can be developed based on these to deal with the IoT dynamics [17]. And if the implementation is based on the swarm intelligence principles, the goals can be easily achieved [18, 19]. In this section, we give an overview of existing swarm intelligence based standard routing protocols. The literature studied so far as to compare the various available algorithms is stated as follows:

Ant Colony Optimization Algorithm (ACO)

Xie Hui et al propose the algorithm ACO in [20] which is clearly bio-inspired and supports the wireless sensor network features such as limited resources (power, bandwidth etc.), self-organization and dynamic routing. The ACO algorithm works under three phases. First, neighbor discovery, in which the routing tables are built based on the broadcast response from the destination. Second, the routing and packet transmission phase, in which the shortest path is chosen depending on the metrics such as delay, energy left with the nodes etc. Third, the route maintenance phase, in which updating of routing tables is done and also nodes are discarded if low on energy level. The experiments are done using the GloMoSim2.0 simulation software. The ACO is compared with the two other algorithms namely, SPEED and EAR (Energy Aware Routing). The simulation area is 5000m x 5000m for the 20 to 120 varying number of nodes. And performance is compared based on the two metrics i.e. node operational time and average energy consumption. The simulation results clearly show that the SPEED algorithm stands on the last place and for less number of nodes network EAR and ACO work more or less same, but for the denser networks, the ACO is the most efficient algorithm.

Ant Agents for Hybrid Multipath Routing in Mobile Ad hoc networks (AntHocNet)

Gianni et al proposed the AntHocNet protocol in [21] for the MANETs. The algorithm is supported by the ACO principle, its self-organizing behavior to find the shortest path for the route disclosure. It is hybrid multipath algorithm that consists of both the proactive and reactive components. The ants are generated as per the hybrid scheme. The paths are discovered at the start of the session i.e. on demand. The ants are generated called as reactive forward ants at the path setup stage and the backward ants are reserved for return path. The pheromone tables are created based on these paths, the tables indicate the values for the path quality metric. The data packets are randomly routed and the paths are improved pro-actively through proactive forward ants. The AntHocNet deals with the link failures through local path repair or by informing the preceding nodes on the route. The authors compared the said

algorithm with the AODV algorithm. The simulation software used for the experiments is QualNet. Initially the number of nodes for the experiment is 100, those are randomly placed in the area 3000x1000m^2 and later on the number of nodes and the area has been increased. The simulation results use the Random Waypoint model and Gauss-Markov mobility model. The results clearly show that the AntHocNet surpasses AODV in terms of delay, jitter and delivery ratio. However, the AntHocNet is less efficient in terms of routing overhead.

Ant Colony Optimization and Ad hoc On-demand Multipath Distance Vector (ACO-AOMDV)

Xun-bing Wang et al proposed this algorithm in [22] for improving the multipath routing performance. The protocol is based on the standard AODV (Ad hoc on demand Multipath Distance Vector) protocol and supported by the ACO principles. The metrics used for the neighbor node selection are hop count, average link count of the route and the average load of the route. Regular updating of the routing tables is done to maintain the dynamic nature of the network for the quality of the service. The protocol works in three phases i.e. route discovery phase, route maintenance and the route failure handling phase. The failure management is done through missing acknowledgement technique. The simulation software used is Network Simulator-2 with the Two-way ground model. The protocols in comparison with this algorithm are AOMDV and ARA. The simulation time taken is 900 seconds with 1500m x 900m simulation area and 50 as the initial number of nodes. The metrics observed for the comparison are the fraction of successful delivered packets, average end to end delay, routing load and routing discovery frequency. Simulation results tell that ACO-AOMDV performance is more or less improved as compared to the other two algorithms in terms of above said metrics. More improvement can be expected if the pheromone concentration at the edges is focused upon.

Probabilistic Emergent Routing Algorithm for Mobile Ad Hoc Networks (PERA)

John Baras and Harsh Mehta proposed this swarm intelligence based algorithm [23]. They state that this algorithm exploits the broadcasting feature of the wireless networks. And it uses the flooding technique to maintain the route discovery process, from source to the destination. Forward and the backward ants are used in the process. These forward ants are responsible for maintaining the probability factor, which tells the goodness or quality of any path for delivering the packets to the desired destination. Following the process, many new paths are created. The forward ant collects the information such as

occurrence of delay in recursive manner, considering sub routes also and the number of hops to be taken on the route. Such feedback for the paths is not available in the standard algorithms such as AODV, DSR etc. The backward ants are created at the destination and are used to retrace the path. It changes the probability distribution at every node and updates the routing tables according to the current network status. And the data packets can be routed using the probability metric in the routing tables. The simulation software used is Network Simulator-2. Every simulation run is for 900 seconds using the Random Waypoint model. PERA is compared with the AODV protocol on the basis of good put (transmission of only useful data through the link), throughput and the average end-to-end delay. In case of throughput at the slow speed, both offer the same speed but at high speed, PERA is not much efficient. PERA shows fewer delays whereas AODV has large delays. And also, good put is less in case of PERA.

Energy-Efficient Ant-Based Routing (EEABR)

Tiago Camilo et al proposed EEABR routing algorithm in [24] which is ACO based for wireless sensor networks. The algorithm deals with WSN issues such as low memory, low processing capability and low energy availability. EEABR utilizes the ant agents such that these help in shortest path discovery from source to the destination, travelling through various sensor nodes. The energy efficient paths contribute towards the overall lifetime of the respective network. Every ant chooses the neighbor sensor node on the basis of the energy quality and the number of hops during the traversal process to the destination. The algorithm is compared with the other two algorithms i.e. the Basic Ant-Based Routing algorithm (BABR) and the Improved Ant-Based Routing algorithm (IABR). The simulation software used in the experiments is Network Simulator-2 with the two-ray ground reflection model. The number of nodes varies from 10 to 100 along with the varying simulated area. The metrics chosen for the comparison are the minimum energy for all the nodes, average energy of the nodes at the end of the simulation, the standard deviation of energy levels of all nodes and the energy efficiency calculated as the ratio of the total energy consumption and the total packets received at the destination. The simulation results clearly show that the EEABR algorithm is very good in energy saving and in minimizing communication load.

Ant-based Dynamic Zone Routing Protocol (AD-ZRP)

Okazaki et al proposed this reactive protocol in [25] based on dynamic zones for WSNs. Based on two other routing protocols i.e. HOPNET and ZRP, it provides improvement in route discovery and maintenance using

pheromones. It deals with dynamic topology issue considering unreliable links and congestion. It takes the advantage of both the protocols, as HOPNET is self-configuring routing protocol supported by zones and ZRP as the hybrid routing protocol to reduce the control overhead and latency of the various proactive and reactive protocols respectively. In the network, the interzone and intrazone route discovery is done. The on-demand transmission changes the shape and size of the dynamic zones. Initially the zones are empty, then after each packet transmission to an unmapped destination, a new route is added in the zone. The simulation software used for the experiments is Global Mobile Information System Simulator (GloMoSim). The simulation is run for 900 seconds and the simulation area is 700m x 400m. The model used is Random Way Mobility (RWP) with number of nodes varying from 20 to 200 confirming to zone radius from 2 to 5. AD-ZRP uses pheromone deposits as the metric for neighbor node selection. The proposed protocol is compared with HOPNET. And the simulation results show that AD-ZRP offers reduced routing overhead, reduced congestion and better packet delivery ratio.

Ant Routing Algorithm for Mobile Ad hoc networks (ARAMA)

Hussein et al proposed the ARAMA algorithm in [26] which is based on swarm intelligence principles to tackle with the dynamic changes in the network. The algorithm is able to produce controlled updating and broadcasting and also reliable path set-up. ARAMA uses the number of hops metric. It brings the optimum use of energy throughout the network. Priority based energy distribution is done to all the nodes in the network. The simulation software used is the OPNET with Waypoint model. The simulation run time is 900 seconds and the 1000m x 1000m simulation area for initial 30 nodes. ARAMA takes advantage of both the on-demand and table based routing protocols. The simulation results show that the ARAMA is good enough in reducing the routing overheads and efficient in extending reliability and survivability of the network.

The dynamic environment and the large-scale nature of networks, the efficient routing algorithms are really needed. This should adapt the various attributes of the networks such as the low bandwidth, low power, multi path and changing topology and the dynamic environment. Some standard protocols are being used to tackle the hefty traffic load and the traffic displacements. But for IOT, only AODV or ARA or such type of standard protocols [27,45] are not sufficient. All the algorithms discussed above and many other swarm intelligence based algorithms are based on the performance metrics such as end to end delay, hop count, packet delivery ratio, energy level of the nodes etc. Many new parameters (discussed in the next section) are expected to improve

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the routing protocols which in turn directly affect several other parameters such as goodput, throughput, jitter or end to end delay etc.

There are some important parameters which may be crucial for the development of the routing algorithms and are listed as under:

- *Multipath:* The main aim of this metric is to provide reliable communication and to improve the Quality of Service (QoS). Many paths are constructed and the best possible path is selected based on the energy of the node, minimum delay, minimum hop count etc.
- *Load Balancing*: Using the multipath metric, a load balanced network can be created. These types of networks are highly desirable as there will be less chances of failure of nodes in the network, thus providing reliable communication.
- *Dynamic topology support*: Dynamic topology means the changing topology or the change in the location of the various devices which are part of the network. Primarily, MANETs should support this metric.
- *Multihop routing:* The communication from the source to the destination involves travelling from various nodes in between. This type of routing is known as multi hop routing.
- *Failure Management*: Node failure is a crucial factor for the routing protocols. Efforts are made to minimize the link failures to support the reliable communication.
- *Network Lifetime Improvement:* By using the multipath parameter and the load balancing parameter, the network lifetime can be improved. As the battery life or the energy in the nodes is limited, constant efforts are made to reserve the same and balance or increase the network lifetime.
- *Link Quality:* This factor is considered to provide the quality of service in the communication. The quality of the path is checked and maintained to minimize the predicted delays and the retransmissions of the payload.
- *Energy Efficient*: The protocols should be in the favor of saving the energy of the nodes. As this is the crucial resource, the routing protocols which are energy efficient are highly desirable. Energy can be taken as the context attribute for some standard routing protocols.
- *Context Aware:* Context aware routing algorithms make use of the context in the routing process. The context can be built upon various factors such as residual energy of the nodes, processing power of the nodes, location and speed of the device etc. Bit Error Ratio (BER) and Packet Error Ratio (PER) factors are maintained for the reliable payload transmission. The Signal Noise Ratio (SNR) can be calculated for the paths and preference to the path is given if the SNR is high, but it also depends on the sensitivity of the content on the channel.

- *Content based:* The protocols may behave in an intelligent manner, if these are proactive regarding the content to be delivered through communication. The content relevancy value can be set and used as the performance metric for the routing protocols. And this vital metric is supported by the two protocols namely ACBRAAM [28] and Predictive routing algorithm [29], as provided in the given table. The routes found on the basis of content reduce the number of retransmissions, unreliable data delivery etc. The content and presentation of data should be taken differently [49].
- *Analog Metrics*: These can be used to find the probability of the goodness of the path for the reliable payload delivery. Protocol such as ABRAAM [33], shows the advantages of using the analog metrics (Angle of arrival, time of arrival and signal strength) such as reduced end-to-end delay etc.
- *Heterogeneity*: The heterogeneity metric can be defined with respect to the various vendors, variety of devices, various manufacturers, various protocols, variety of hardware and software etc. The standard routing protocols are desirable which can easily switch between the heterogeneous environments. And in the given table, no routing algorithm provides support for heterogeneity metric. In case of IoT, it means the way in which the communication networks are arranged. There are two ways heterogeneity can be defined, the physical distribution of cables, relays, servers etc. or the way the information to be sent is structured and arranged.

Naker Khalil et al in [35], discussed the methods of integration of WSNs into IoT. The paper mentions that the devices involved in a WSN are using one way communication protocols but should use two-way communication protocols and should react to the user commands. The paper identifies the challenges involved in the switch over of IPv4 to IPv6 and in two-way com-munication protocols. They suggest that some middleware can be used to mask the heterogeneity in the system and to hide the details from the clients. The clients can use the virtual system of using IPv4 and can connect to the WSN which is using IPv6, some switching needs to be done from IPv4 to IPv6 and vice versa. The 1280 bytes IP packet can be reduced to 127 bytes Zigbee packets.

CONCLUSION

Routing is the major challenge for the payload delivery from the source to the destination in the network [1-5]. Several significant factors are missing in case of all the existing protocols available for MANETs and WSNs. The existing protocols do not solve all reliability issues and efficient routing is

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not achieved still completely [30]. As of now, no techniques or protocols are efficient enough to cover all the issues and provide the solution [34]. There is a need to develop new protocols for the communication which will cater all these needs. The different important points to be considered are as follows:

- *Routing*: There are various routing algorithms available for MANETs [1, 23] and WSNs [8, 10]. But there are no standard algorithms exist for IoT. The routing algorithms available for MANETs are not applicable to IoT because IoT focuses more on Machine to Machine communications and deals with smart devices [18].
- *Analog Metrics*: The significance of analog metrics (Angle of arrival, Time of arrival and Signal strength) has not been fully explored to discover the sustainable and durable links or paths for the successful payload delivery [33].
- *Signal Noise ratio*: The existing standards are not considering the effect of noise in the routing and payload delivery process fully, it is not found any heuristic approach of content delivery in IoT based on Signal Noise Ratio (SNR) [28,29,46,51].
- *Heterogeneity:* As internet is transforming into IoT, it introduces the level of complexity with respect to interoperability (such as vendor interoperability) [50] or heterogeneity of things like RFIDs, sensors and other devices. The standard protocols are lacking in handling the same. Two important issues need to be considered, firstly, implementation of IPv6 over 6LOWPAN (to connect every small device in IoT) and secondly, standardized protocols for the machine to machine communication [35-37,39].

Efficient and scalable routing protocols adaptable to different scenarios and network size variation capable to find optimal routes are required [31,32,38]. The usage of ACO principles in the routing algorithms, prove to be bright for the route optimization issues.

IoT represents the next evolution of the Internet. Given that humans advance and evolve by turning data into information, knowledge, and wisdom, IoT has the potential to change the world as we know it today—for the better [47]. But along with the transition there are several challenges or issues which need to be resolved. Only after we overcome all the issues, such as routing and heterogeneity etc., we will be able to taste the benefits of the future technology. The existing protocols are not sufficient, need to implement more routing protocols for routing in IoT [40]. Packet routing performance [41] is required to be boosted to enhance the capability of overall IoT system [42].

The usage of ACO principles in the routing algorithms, prove to be bright for the route optimization issues. The importance of the relatively new parameters like heterogeneity, content relevancy and analog metrics has also been analyzed. It is worth noticing that the inclusion of these parameters along

with others increases the efficiency and improves the routing process. The routing protocols which are content based or analog metric based (ABRAAM, ACBRAAM or Predictive Routing algorithm) are expected to perform more efficiently and effectively.

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