Architecture and Routing Protocols for WPAN Networks

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ABSTRACT: *We in this paper have provided 6LoWPAN architecture and description of various routing protocols. We have analyzed various routing requirements in the 6LoWPAN networks and also tried to understand the architecture. We have also tried to classify the routing protocols in the 6LoWPAN network and we found that four main groups of protocol could be formulated.*

Keywords: Wireless Sensor Networks, IPv6, Routing Protocols, 6LoWPAN, Constrained Devices

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1. Introduction

Wireless sensor network (WSN) is one of the fastest growing area in networking today. WSN finds numerous applications in different areas like home automation, healthcare, industrial and environment monitoring. Most of these applications can have real impact into monitored system if gathered data can be processed and controlled over Internet. In order to meet the requirements of resource constrained devices used in WSN and to give the possibility to interconnect them to the Internet, IPv6 low power personal area network (6LoWPAN) is introduced [1]. 6LoWPAN can be considered as an adaptation layer above the IEEE 802.15.4 link layer with the main aim to help packet fragmentation and reassembly. The major function of the adaptation layer is not only the TCP/IP header compression but routing also.

During the last decade, a number of different routing protocols developed especially for 6LoWPAN has been proposed in the literature [2]-[15]. Although, the number of routing protocols are proposed, some of them are not adopted and are not become an accepted standard. Different types of routing mechanisms are used in 6LoWPAN based on the topologies and applications running over it. Mobile nodes and dynamically adaptive topologies should be allowed in 6LoWPAN routing protocols. The main aim of this paper is to present, study, compare and evaluate different adaptive and modular approach to routing in 6LoWPAN networks and to classify them. After a carefully analysis and comparison of the possible routing protocols the best solutions and recommendations are presented.

This paper is organized into 5 sections. The 6LoWPAN technology constraints are considered in Section 2. Different routing protocols are analysed in Section 3. In Section 4, a classification is proposed and a comparison of the routing protocols is performed. Concluding remarks are presented in Section 5.

2. 6LOWPAN Limitations

There are certain considerations for the 6LoWPAN while communicating with the other IP based networks. As the number of the nodes grows in the 6LoWPAN network, the auto configuration and statelessness are strongly required, thus 6LoWPAN network interconnects to the other IP networks by IPv6 [1].

The 6LoWPAN architecture is given in Figure 1. As it can be seen the IEEE 802.15.4 physical and MAC layers are adopted and IEEE 802.15.4 frame format must be followed. The limited packet size must be taken into account while designing routing protocols for such type of network. As the size increases more than the 127 bytes, it poses challenges for the low end 6LoWPAN nodes, as they do not have enough RAM or memory to accommodate 1280 bytes IPv6 packet size [1].

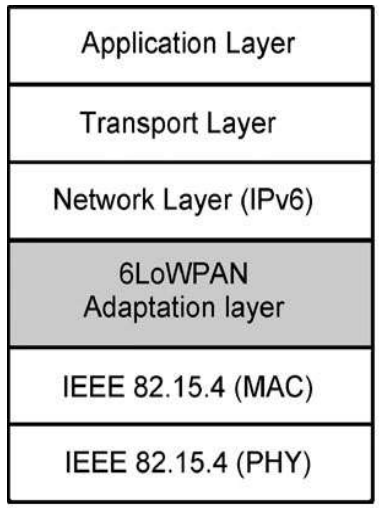

Figure 1. 6LoWPAN architecture

Because of the sustainable interest towards the WSN and also the services they offer, the number of the 6LoWPAN nodes increase significantly and these devices have limited input and display capabilities as well as can be located in hard to access locations. Thus the protocols used in 6LoWPAN devices should have minimal configuration, be easy to bootstrap and enable the network to self-heal of these nodes for inherent unreliable characteristics. The size constraint for the link layer protocol should also be considered. The management of network should have little overhead, but powerful enough to control dense deployment of the nodes in the network [1].

Service discovery protocols are required by the 6LoWPAN network to discover, control and maintain services provided by the nodes. Confidentiality and integration protection are required by the 6LoWPAN applications, which are provided by the all layers above the PHY layer. Small code size, low power consumption, low complexity and small bandwidth are the some of the prevailing constraints that can affect the choice of a particular protocol.

Location information of the nodes in the network is used to determine the place of the occurrence of the phenomenon and it also helps for the development of energy efficient routing protocols. Location information and IP addresses can be used to reduce the overhead of the transmission. Different challenges for the 6LoWPAN networks like failure of the node due to lack of power, physical damage or environmental interference leads to rerouting or re-organization of the network.

3. Routing Protocols

After a deep study of the existing literature, it can be seen that the developing of new routing protocols addressing all of the 6LoWPAN issues is still an open research area. The existing routing protocols could be classified based on different criteria as it was given in [2]-[15]. In this paper new classification is proposed leading to more clearly and understandable way to explain and compare the features of the existing routing protocols. Four main groups of routing protocols as it was given on Figure 2 could be formulated.

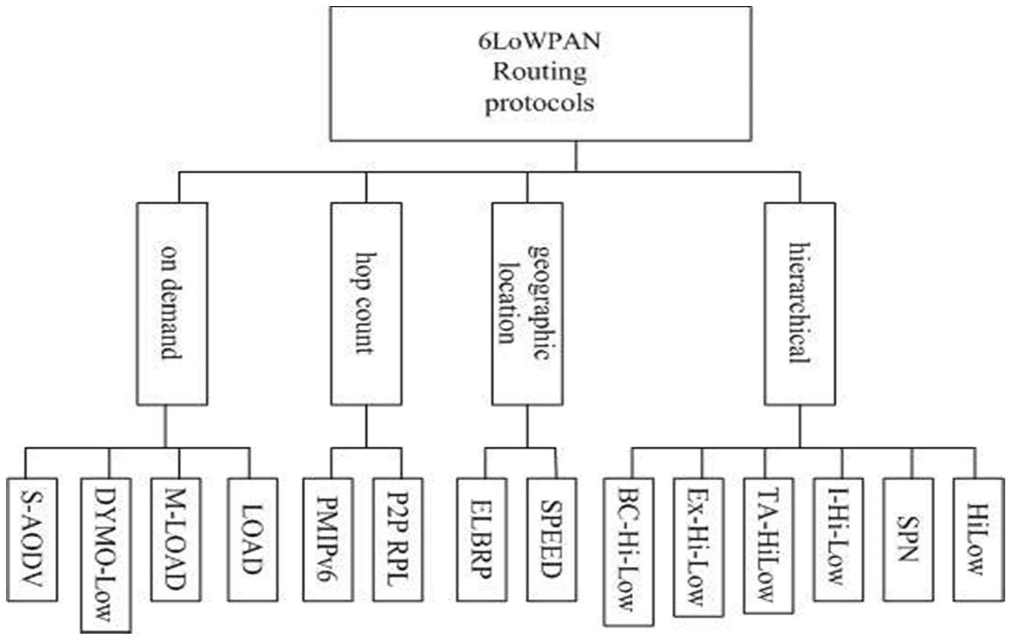

Figure 2. Classification of 6LoWPAN routing protocols.

3.1. On Demand Routing Protocols

6LoWPAN Ad-Hoc On-Demand Distance Vector Routing (LOAD) is a simplified on demand routing protocol, defined to be working on top of the adaption layer instead of transport layer [2]. The basic operations of LOAD are route discovery, managing data structures and maintaining local connections. For these operations, LOAD maintains the following two tables: the routing table (storing information such as destination, next hop and status) and the route request table (storing the temporary route information used in the route discovery process) [2]. In order to reduce the size of control messages and to simplify the route discovery process, the use of destination sequence number are omitted. Route Reply message (RREP) is generated only by destination of a route ensuring loop free condition. If a local repair fails, Route Error message (RERR) is forwarded only to the originator of the failed data delivery, thus no requiring to use the precursor list. LOAD uses number of hops and Link Quality Indicator (LQI) route metrics from source to destination to determine the strongest route. It also uses the Acknowledgement messages (ACK) to ensure guaranteed delivery of packets.

In order to overcome the energy consumption problem in LOAD, Multipath LOAD (M-LOAD) protocol is proposed in [3]. Energy consumption is high in LOAD protocol due to repeated broadcast of Repeat Request message (RREQ) for route discovery process. M-LOAD is designed to reduce the network overhead. It enhances the LOAD protocol to find multipath routes during path discovery process by implementing the Ad-hoc on-demand multipath distance vector routing (AOMDV) on LOAD.

Dynamic MANET on-demand routing for 6LoWPAN

(DYMO-Low) is another routing protocol operating on the link layer directly and thus creates a mesh topology with the 6LoWPAN devices, so that IP can see the WPAN as a single link [4]. DYMO-Low provides an easy and effective method of implanting routing protocol. It uses both 16 bit short addresses and 64 bit extended addresses.

Sink Routing Table over Ad hoc On Demand Distance Vector (S-AODV) designed in [5] reduces the power consumption, provides load balancing and enhances the network lifetime. Routing table is maintained by the Sink node and it forwards the query packets to the specific internal node using the routing table. Response of the destined node to the query of sink node is given through the neighbouring node. It has setup phase and steady state phase, sink node broadcast its status to the nodes in the network and every node in the set-up phase establishes its path to the sink node through the optimal neighbour node. Sink node uses this information to construct a Sink Routing Table (SRT). Data is transferred in the steady-state phase between the sink node and destined common node [5]. With the help of this mechanism, the delay and the energy consumption is minimised during data forwarding in the network.

3.2. Hierarchical Routing Protocols

Hierarchical Routing in 6LoWPAN (HiLOW) is developed to increase the scalability and uses the 16 bit short address as interface identifier for memory saving and larger scalability [6]. It exhibits parent child model and every node in the network discovers its parent by sending the broadcast signal. If the node finds a 6LoWPAN parent node in its Personal Operating Space (POS), it gets associated by the parent node using 16 bit short address otherwise it configures itself as coordinator. The different child node receives a 16 bit short address from its parent node in the network. When a node wants to send a packet to destination, it determines the next hop node to forward the packet. If a link failure occurred in the network, no route recovery path mechanism is performed to repair the route resulting in unguaranteed packet delivery of packets in the network.

Step Parent Node (SPN) [7] is a new path recovery algorithm developed to improve the existing HiLow protocol in [6]. When a link break happens in the network, the child node of the failure parent node broadcasts a step parent node request message to his neighbouring nodes, which unicast a step parent node message reply to the sender, if he has the child nodes value less than its MC value (MC=4). If the requesting node gets more reply messages, then it will check the Path Quality Indication (PQI) and address of different senders. It will get associated with that node, which has high PQI and not the descending of the sender. To improve the network scalability, 16-bit short addresses are used in this algorithm.

Improved HiLow (I-Hi-Low) [8] is used to increase the efficiency of the protocol. The current node broadcast "Hello" message in its Personal Operating Space (POS) to acquire information about its neighbours in this Improved High Low protocol. The current node "C" calculates its Parent address using the equation "AP= [(AC-1)/MC]" after receiving the packet from neighbouring node. Improved hierarchical routing protocol takes minimum hop counts to reach its destination while comparing with existing hierarchical routing protocols.

Light weight address allocation and addressing schemes are the main features of hierarchical routing protocol. A hierarchical tree is established between parent and child node to transmit the packets. Address allocation and routing mechanism are the main problems in the existing hierarchical routing protocol. A new mechanism is suggested in Bias Routing Tree Avoiding Technique for Hierarchical Routing Protocol for 6LoWPAN (TA-HiLow) [9] to avoid the bias routing tree that could happen if the child node do not attach to the parent node evenly. Attached child number information is transmitted to avoid the bias routing tree problem.

Extended Hierarchical Routing (Ex-Hi-Low) [10] mechanism configure a hierarchical routing tree in this protocol and if a sensor or parent node fails due some reasons the routing tree structure cannot be maintained. New child node sends a packet and destination node ID to parent and parent sends the path information of the destination to coordinator node. The coordinator node sends this information to router nodes to check their routing table for Neighbour Added Child (NAC) information and router sends the reply to the coordinator node. After this process the new child node sends the packet to the destination via his new parent node.

If a child node has more than one potential parent node and the child attaches to the first responding parent node, this situation leads to uneven or biased child distribution system and short span of life for the 6LoWPAN network.

The new developed protocol Bias Child Node Association Avoidance Mechanism for Hierarchical Routing Protocol in 6LoWPAN (BC-Hi-Low) avoids a biased hierarchical routing tree structure considering the potential parent node's depth, energy level and signal strength [11] . The potential parent node provides the child node with its existing child node count, by this count the new node selects its parent with less child nodes. The performance of this protocol [11] will be better if the parent node has same energy level, same depth and different child nodes, if it is same then it again leads to bias child node association. In this mechanism the new child is provided the depth and the average amount of power of the parent node. The average amount of the power is calculated by the equation Avg = CBP/(CC+2) where CBP is current battery power and CC is current child node.

3.3. Geographic Location based Routing Protocols

SPEED Routing Protocol in 6LoWPAN Networks is designed for providing soft real time communication in 6LoWPAN networks. Geographic position and global addresses are used to identify the packets sent toward it destination nodes and the destination area is recognised by the central position and radius. Shortest path is used to send the nodes towards the destination and SPPED [12] supports for load balancing, soft real time and flow shaping mechanism for making this protocol an efficient solution in the 6LoWPAN networks for packet routing.

In Enhanced Location Based Routing Protocol for 6LoWPAN (ELBRP) [13] protocol the geographic location is used as a routing metric for transmission of packets in the 6LoWPAN network. The sink node broadcast its location information and address during the network initialisation, the other LER and RFD nodes of the network uses this location information, distance and LQI as a routing metric for communication. LER sends a RREP in unicast manner, in reply the source node sends the RREQ message and only the nearby LERs reply for that node and neighbour table information is filled in the source node. Between the LERs based on maximum distance, the best LER is chosen and this LER reply the RREP message. Each node of the network maintains a routing table and neighbour table. Routing table of node contains ER address, ER location, source address and source location and neighbour table of nodes stores the ER address, its location and LQI. Energy consumption of this protocol is also very low.

3.4. Hop count-based Routing Protocols

Point to Point Routing Protocol for Low-Power and Lossy Networks (P2P RPL) [14] allows router to discover and establish paths to another router, based on a reactive mechanism. When a router S needs to discover a path to another router D, the first router S originates a message similar to an AODV- Route Request. This protocol has introduced a new destination-oriented directed acyclic graph (DODAG) Information Objects option that specifies an address which should be discovered and records the traversed path.

Different protocols for 6LoWPAN mobile sensor node (6LoWMSN), based on Proxy Mobile IPv6 (PMIPv6) [15] have been introduced. The PMIPv6 standard supports only single hop networks and can't be applied directly to multi hop based 6LoWPAN. This protocol does not support the mobility of 6LoWMSN and 6LoWPAN gateways and can't detect the attachment of PAN to 6LoMSN. The mobility in the multi hop based 6LoWPAN networks is introduced with the movement notification of a 6LoWMSN. Router solicitation (RS) and router advertisement (RA) messages are used to reduce the signaling cost over the wireless link with the attachment of 6LoMSN. PAN attachment detection scheme for 6LoMSNs is defined to apply the single hop based PMIv6 protocol to multihop based 6LoWPAN networks by using router solicitation (RS) and router advertisement (RA) messages.

features	M-LOAD	S-AODV	SPN	BC-HILOW	HI-LOW	PMIV6	SPEED	ELBRP
RERR msg	use	use	no use	no use	no use	no use	no use	no use
energy usage	low	low	low	low	low	high	low	very-low
broadcasting rreq	high	reduced	high	reduced	high	reduced	reduced	reduced
sequence no	use	no use	no use	no use	no use	use	no use	no use
hop count	use	use	no use	no use	use	use	use	use
hello msg	no use	no use	no use	no use	no use	no use	no use	no use
node mobility	mobile	mobile	mobile	mobile	static	mobile	static	mobile
convergence to topology	fast	fast	slow	fast	slow	slow	slow	fast
PQI	no use	no use	use	no use	no use	no use	no use	use

Table 1. Routing Protocol Comparison

4. Comparison of Routing Protocols

Because of the limited size of the paper, only some of the routing protocols are compared and the results are presented in the Table 1. It is observed in our comparison that LOAD, DYMO-Low, M-LOAD, and S-AODV protocols utilize the RERR message to indicate the link breakage in the networks, while the other protocols not utilized this feature. All the protocols consumes very less energy and LOAD, M-LOAD, DYMO Low, Hi-Low and SPN broadcasts the RREQ for route discovery. DYMO-Low uses sequence number for freedom of loops while other protocols do not use this feature. Hello message is used only in DYMO-Low and I-Hi-Low for tracking the neighboring nodes constantly. Hi-Low, MLOAD, S-AODV, I-Hi-Low and ELBRP uses the concept of hop count as a routing metric and the process of local repair is used in LOAD to determine alternate link for data forwarding while alternate path as identified in case of M-LOAD.

All the nodes support node mobility except the SPEED protocol and the mobility of sink is addressed in S-AODV in contrast to other protocols. In the protocols Hi-Low, SPN, IHi- Low, TA-Hi-Low, Ex-Hi-Low and BC-Hi-Low scalability analysis has been performed in comparison with other protocols. DYMO-Low has high routing delay as compared with other protocols. SPN and ELBRP utilized Path Quality Indication (PQI) as routing parameter as compared to other protocols. HiLow, SPN, and SPEED has slow convergence to varying topology in comparison with other protocols. P2PRPL and PMIV6 has used multi hop as a routing metric while comparing with other protocols in the 6LoWPAN networks.

5. Conclusion

In this paper we have analyzed various routing requirements in the 6LoWPAN networks and also tried to understand the architecture. We have also tried to classify the routing protocols in the 6LoWPAN network and we found that four main groups of protocol could be formulated. We found many issues still need to be addressed in this area and the routing algorithm need to be optimized for different reasons.

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