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6LoWPAN Routing Issues

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ABSTRACT:

6LoWPAN (IPV6 over Wireless Personal Area Network) is a wireless personal area network that contain devices compatible with IEEE 802.15.4. Routing is the major issue in 6LoWPANs as the nodes are characterised by scarce memory, limited power, low battery life, limited resources and less cost. Routing protocols for such networks should be designed such that they make efficient use of available resource and should exhibit high performance. This paper presents a detailed survey of 6LoWPAN routing protocols, their comparison on several metrics such as memory power, power consumption, scalability, routing type, location information and many other factors.

Keywords: 6LoWPAN, Routing

1. INTRODUCTION

Wireless Sensor Networks (WSN) is the area where majority of research work is taking place. WSN finds its application in military, Home automation, Industry automation, Hospital management, defence, Security, Smart grids etc. What comes in the near future is that all embedded devices characterised by low power, scarce memory capacity, small size, less cost to be connected through the Internet. That is, Internet of Things. Wireless Embedded Internet is a subset of Internet of Things.

The lack of an IP-based network architecture prohibited sensor networks from interoperating with the Internet. Considering this drawback, the IETF initiated the 6LoWPAN and RoLL working groups in order to define standards at different layers of the existing protocol stack to achieve the connectivity between low-power, lossy networks and the Internet. 6LoWPAN working group uses the standard IEEE 802.15.4 PHY layer and also describes how to transfer IpV6 packets over IEEE 802.15.4 networks.

A LoWPAN is a collection of 6LoWPAN nodes that have first 64 bits of IpV6 address as common. LoWPANs are divided into Simple LoWPAN, Extended LoWPAN and Ad-hoc LoWPAN. The architecture of LoWPAN is shown in fig.1.1. Simple LoWPAN consists of several LoWPAN nodes connected to the Internet via backhaul link and an edge router. An extended LoWPAN is a collection of LoWPAN nodes in a larger scale which in turn are connected to the Internet through two or more edge routers and a backbone link. LoWPAN can also operate without infrastructure, called as Ad-hoc LoWPAN, where a LoWPAN node is configured as a simple edge router. Here the IpV6 prefix used is local, not global. The Edge routers showed in the figure routes the traffic in and out of the network. They also handle neighbour discovery, 6LoWPAN compression and IpV4 interconnectivity. A LoWPAN node may act as a node or as a router including the edge router. LoWPAN nodes can participate in one or more LoWPANs (multi-homed) and they are free to roam around in LoWPAN and across LoWPANs. Communication between LoWPAN and IP Network is carried out in an end-to-end manner. Each node in a LoWPAN network is identified by unique IpV6 address, with the help of which they are able to send IpV6 packets. LoWPANs support ICMPv6 messages and they use User Datagram Protocol as transport layer protocol.

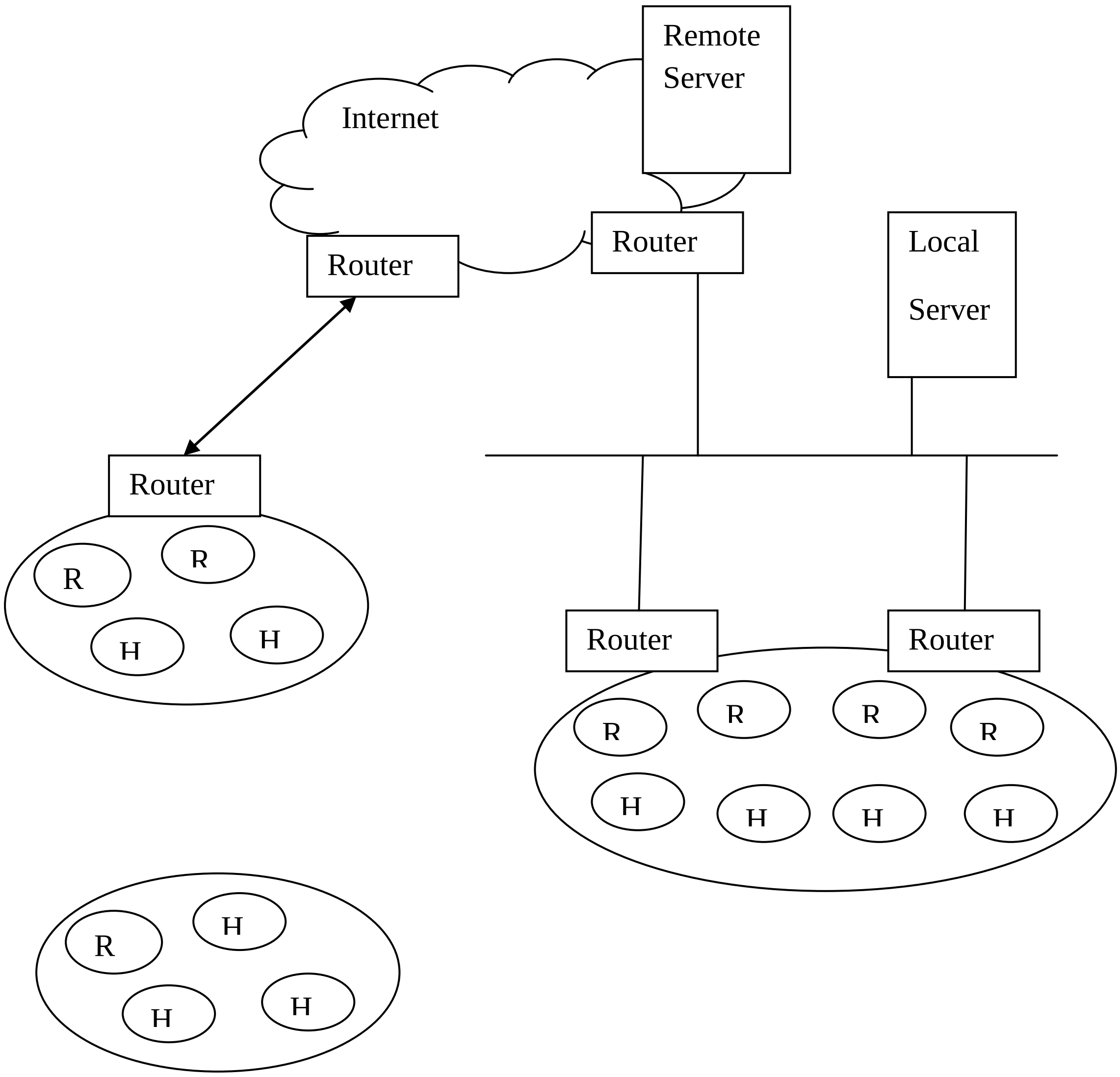

Fig.1.1 architecture of 6LoWPAN

The rest of the paper is organized as protocol stack of 6LoWPAN, routing parameters and requirements, different routing protocols, comparison of routing protocols, conclusion and references.

2. Protocol stack of 6LoWPAN:

In a LoWPAN network some nodes restrict themselves to the role of hosts only but only few nodes may take part in routing also. The nodes that perform routing have more processing and storage capabilities. Fig. 2.1 shows IP protocol stack in comparison with the 6LoWPAN protocol stack.

Physical layer provides the basic communication capabilities. It is compliant with IEEE 802.15.4 and provides a data rate of 250kbps operating frequency of 2400-2483.5MHz and it supports a maximum payload of 127 bytes. Datalink layer enables reliable single-hop communication links between devices. LoWPAN is a non-beacon enabled network where data frames are sent via contention-based channel access method of Unslotted CSMA/CA. Adaptation layer is the most important layer of the 6LoWPAN. It performs TCP/IP header compression. IEEE 802.15.4 has a packet size of 128 bytes. But IpV6 header occupies 40 bytes header. UDP and ICMP both has 4 bytes header size and TCP occupies 20 bytes as header. So LoWPAN cannot transmit the data effectively without performing header compression. Adaptation layer handles fragmentation and reassembly. IpV6 has Maximum Transmission Unit of 1280 bytes while IEEE 802.15.4 has a packet size of 128 bytes. So this mismatch is handled in the adaptation layer. The major function of the adaptation layer is routing, where border WSNs should be able to route the packets to and from the LoWPAN and outside IP network. Adaptation layer also supports neighbour discovery and multicasting. Network layer provides Internetworking capability with the sensor nodes, provides security services, helps in network management using Simple Network Management Protocol (SNMP). Transport layer performs process-to-process delivery.

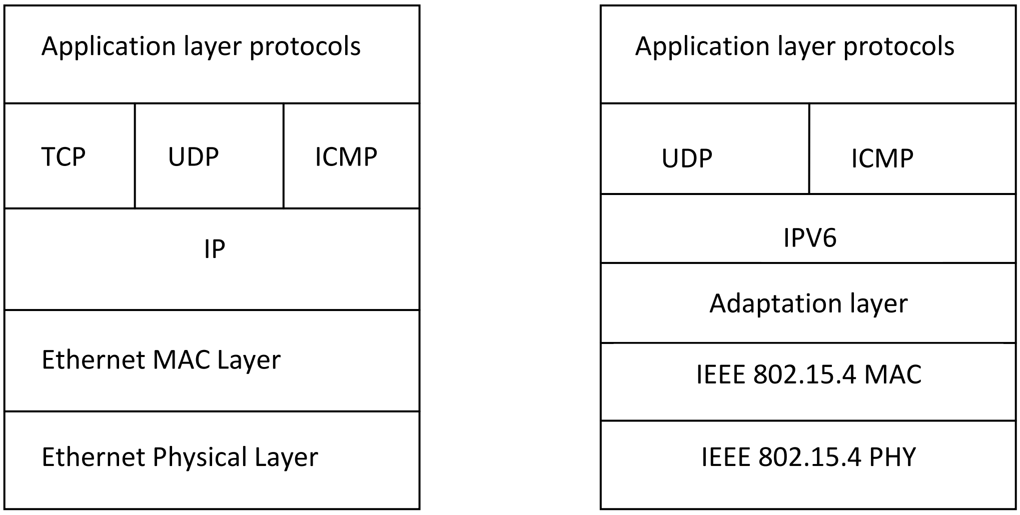

Fig.2.1 Protocol stack of TCP/IP and 6LoWPAN

The term Routing usually refers to the formation of paths and forwarding of packets at the IP layer. But in LoWPANs routing can occur at the IP layer or below IP layer. There are four requirements defined for 6LoWPAN routing protocols, which are- low overhead on data packets, low routing overhead, minimal memory and computation requirements and support for sleeping nodes. The transmission of IpV6 packets over LoWPAN is difficult because of increased address space from 32 bits to 128 bits and minimum MTU of 1280 bytes whereas the required minimum MTU for IEEE 802.15.4 data link layer is 127 bytes. So, to support transmission of IpV6 packets over LoWPAN, an adaptation layer has been implemented between network and data link layer. Because of the adaptation layer, routing or forwarding decisions are taken either at the network layer or at the adaptation layer and also it eases IP packet transmission by header compression and fragmentation to support minimum MTU.

There exists number of IP routing protocols. But those existing routing protocols does not act according to the requirements of the 6LoWPAN nodes, because of the reasons like:

6LoWPAN routing protocols should support multiple device types and roles.

6LoWPAN routing protocols should exhibit better performance as 6LoWPAN nodes are having limited power, low battery life and small memory.

They should be able to handle sleeping nodes as 6LoWPAN nodes stay in sleep for most of the time.

Considering above reasons, routing protocols are designed specifically for 6LoWPANs.

3. Routing Parameters and Routing Requirements:

The parameters that are used to evaluate the routing protocols are as follows:

1) Network parameters:

-number of devices, density and network diameter are taken into consideration as these parameters affect the routing state i.e., the number of entries in the routing table.

-a LoWPAN node can be in several states ranging from "always connected" to "rarely connected" which affects dynamic discovery of routes across 6LoPWAN.

-LoWPAN nodes are highly dynamic. They can be added or removed dynamically from the network. This affects the routing state and the volume of control messages.

-the deployment might occur at once or iteratively which may affect the routing state.

-spatial distribution of nodes (whether they are placed on a grid or located randomly in an area), the number and the spatial distribution of gateways affects the network connectivity, network congestion and available data rate.

-according to different traffic patterns (point-to-point, point-to-multipoint or multipoint-to-multipoint) and different network architectures different routing protocols have been developed such as event-driven, data-centric, location-based and address-centric.

-routing protocols developed should support multiple class of service keeping in mind that LoWPANs are resource-restricted.

-the routing protocols should ensure the security of data carried by LoWPANs along with providing optimizing overhead and power consumption.

2) Node parameters:

-processing speed, memory size, queuing strategies and queue buffer sizes affects the routing state and maximum complexity of its processing.

-the number of battery powered and mains powered nodes and their positions in LoWPAN topology affects routing protocols in selecting the optimized routing path.

-transmission also affects routing.

-highly loaded nodes have higher delivery delays and higher energy consumption than lightly loaded nodes. So traffic patterns affects routing.

3) Link parameters:

-throughput

-latency

There are several requirements for 6LoWPAN routing protocols, which are as follows:

1) Support of 6LoWPAN device properties:

-the protocol running on a node depend on node type and its role. If the node is battery powered then the implementation of routing protocol should have small code size and smaller routing state to fit in the capacity of that node.

-Routing protocols should make efficient use of control packets and there by consuming less power.

2) Support of 6LoWPAN link properties:

-in order to minimize power consumption, fragmentation is avoided wherever possible. So 6LoWPAN routing does not allow packets to exceed the size of IEEE 802.15.4 frame size.

-depending on the application requirement 6LoWPAN routing should ensure successful end-to-end delivery of packets.

-the routing protocols must consider link latency requirements and its characteristics.

-6LoWPANs are unreliable due to their limited system capabilities. So routing protocols should be adaptable and robust to the dynamic environmental changes like link failure, device unavailability, hardware breakdown, operating system misbehaviour etc

-in the presence of link asymmetry, routing protocols should operate correctly.

3) Support of 6LoWPAN network characteristics:

-inorder to save energy LoWPAN nodes may go into sleep for a short span of time despite of which the routing protocols should ensure successful packet delivery.

-routing protocols should be able to select the routing path that balance the tradeoff between the power consumption and packet delivery ratio.

-routing protocols should be scalable.

-the route repair mechanism and the related control messages should not increase the overall energy consumption.

-the routing protocol should be adaptable to dynamically changing topology. Routing protocols should be able to deal with mobile nodes changing their locations inside the 6LoWPAN, movement of LoWPAN with respect to other connected LoWPAN and nodes permanently joining or leaving the LoWPAN.

-6LoWPAN can have different traffic patterns like point-to-point, point-to-multipoint, multipoint-to-multipoint. A routing protocol should be able to support different traffic patterns.

4) Support of security:

-6LoWPAN routing protocols should not compromise the confidentiality, authentication and integrity services.

5) Support for mesh under forwarding:

-mesh under routing requires operation below IP layer. Routing protocols must be able to support 16-bit short and 64-bit extended MAC address.

-To perform neighbour discovery 6LoWPANs should avoid sending Hello messages. Instead it should make use of link layer mechanisms like acknowledgements.

-routing protocol can employ mechanisms that minimize the link layer broadcast.

6) Support of management:

-routing protocols are designed in a way that they are easy to operate , manage and maintain.

Based on application scenarios routing protocols are classified as flooding, data-aware routing, location-based routing, probabilistic routing, event-driven, query-based routing and hierarchical routing. In data centric routing queries on particular data is sent from base station to the network. A node holding the answer replies back. It supports redundant transmissions. In hierarchical routing several nodes grouped together to form a cluster. A node will be assigned as a Cluster Head (CH). CH aggregates data from its cluster members using standard data fusion techniques. In location based routing, geographic location of nodes is used to transmit information. They help to achieve power optimization and minimize control overhead. Based on route discovery process routing protocols can be classified as pro active, reactive and hybrid. Pro active routing protocol calculates routes in priori. So they are best suited for static networks. In reactive routing protocols routes are calculated on demand. So they are applied to dynamic networks. Hybrid is the combination of these two protocols. Based on the layer at which routing takes place, routing protocols are divided into route-over and mesh-under routing. If routing is handled by the network layer then it is called route-over routing and if it is handled by the adaptation layer then it is called mesh-under routing.

3.1. Mesh-under and route-over routing:

In mesh-under routing, forwarding/routing decisions are taken by the link layer based on 802.15.4 frame or 6LoWPAN header. To complete a single IP hop, multiple link layer hops are used and hence the name mesh-under. The link layer source address and destination address are included inside 6LoWPAN header and hence it is possible to forward packets in the adaptation layer. It uses EUI 64 bit address or 16 bit short address. Adaptation layer fragments the IP packet and each fragment is transmitted through mesh routing to reach the final destination. Different fragments can take different paths and they are reassembled at the destination. If any fragment is missing then the whole IP packet is retransmitted to the destination as a packet loss recovery mechanism.

In route-over routing routing decisions are taken at the network layer. Here each link layer hop is an IP hop. Routing takes place with the help of IP routing tables. The adaptation layer builds direct mapping between the frame and the IP headers. The fragments at adaptation layer are sent to the next hop based on routing table information. The adaptation layer at the next hop checks if all the fragments are received properly. If so, it creates an IP packet and forwards it to the network layer. The network layer, if the packet is destined to itself, forwards it to the transport layer. Otherwise forwards the packet to the next hop based on routing table information. If any fragments are missing then all the fragments are retransmitted to one hop distance. After receiving all the fragments successfully it creates IP packet and forwards it to the network layer.

4. Different routing protocols in 6LoWPAN:

4.1. The 6LoWPAN Ad hoc Routing Protocol(LOAD)

LOAD is a simplified form of On-Demand Routing Protocol (AODV) for 6LoWPAN. LOAD operates on adaptation layer of the 6LoWPAN, LOAD is designed to find an optimized route with minimum Route Cost (RC) between two nodes in a network by generating and forwarding broadcast RREQ messages towards the destination during a discovery period. The optimum discovered route is then examined and being communicated to the originator by generating a unicast RREP message at the destination and forwarding it to the originator. While LOAD supports the use of both the EUI-64 and the 16 bit short addressing for routing.

Using LOAD Each node is required to accommodate two tables : Routing Table, which include Destination Address, Next Hop Address to the destination, Status of a route and Life Time of a route before being expired. Route Request Table, which is maintained during the route discovery to keep track of RREQ messages. It includes RREQ ID which is a sequence number to uniquely identify a RREQ, Originator Address of a RREQ, Forward Route cost from the originator to the current node, Reverse Route Cost from destination to current node and Valid Time of the entry before being expired.

Following messages are used to establish a route:

RREQ is a broadcast message originated by the source node and forwarded by middle nodes to the destination. The main field of the message include: Route Cost, RREQ ID, number of Weak Links WL and Destination Adresses.

RREP is a unicast message originated by the destination node and forwarded by intermediate nodes along the discovered route to the source. The message include following main fields: Route Cost, RREQ ID, WL and Destinetion Address.

4.2. S-AODV:

In S-AODV, routing table is maintained at the sink node. This protocol consists of set-up phase and steady phase. In set-up phase, connection is established between the internal nodes and the sink node via optimized path. In steady phase data transfer takes place to and from the destined node through optimized path. Query packets are sent from sink node to the internal nodes. The destined node replies back to the query.

Advantages of S-AODV is minimized power consumption, extended network life time and load balancing in the network. The delay and energy consumption in the network while forwarding packets is minimised to an extent.

4.3. HiLow:

In HIERAR, nodes are grouped together to form a multi-level hierarchy of clusters. At level 0, a singleton node itself forms one cluster. At level 1 neighbouring singleton clusters are logically grouped and this procedure continues until some top level clusters are logically grouped together to form top level cluster that covers the whole network. Each cluster has a cluster head assigned. A level-i cluster is advertised to R_i hops away from its head. Level-i cluster is denoted using the notation C^i_x where 'x' is the cluster head. Each node is identified by a unique identifier. For example, if a node is denoted as P.O.L then it indicates that a node belongs to level 0 cluster with 'P' as cluster head, level-1 cluster with node 'O' a cluster head and level 2 cluster with cluster head 'L'. Fig. 4.1 depicts the HiLow routing mechanism.

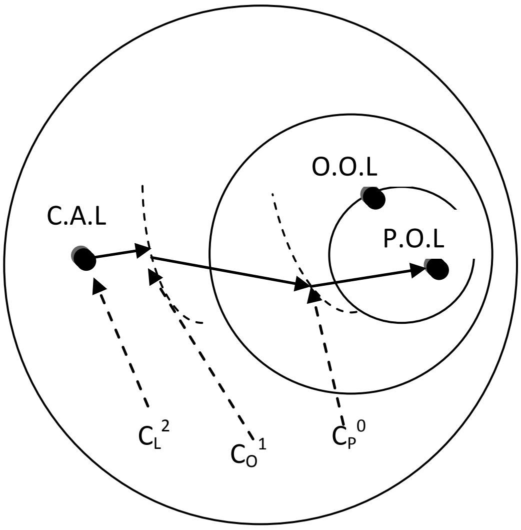

Fig. 4.1 HiLow routing

A node's routing table contains entries for all the cluster heads from which it receives advertisement. Each entry consists of level and identifier of head, as well as the link-layer address of the next-hop neighbour on the shortest path to the cluster head and the length of this path.

Routing takes place hierarchically. If suppose node 'C' labelled as C.A.L wants to send packet to node 'P' labelled a P.O.L then node 'C' first routes the packet to top-level cluster head of node 'P' that is node 'L'. Node 'L', then searches for next decreasing level cluster head in its routing table and routes the packet to node 'O' which in turn routes the packet to node 'P'. So when the packet arrives, the forwarding node will always look for the top-level cluster of the destination node in the routing table entry.

4.4. Improved Hi-Low:

HiLow makes the task of routing too simple by assigning 16-bit short address dynamically in order to establish a hierarchical tree between parent and its children. But this routing protocol suffers from performance degradation as a node tries to communicate with its nearby node over several hops. Improved HiLow boosts the performance of HiLow.

The current node, that receives the packet, identifies its parent through this equation:

AP=[(AC-1)/MC]

AP = parent node address

AC = current node address

MC = maximum number of children allowed

[] indicates the floor operation.

The next hop to which the packet should be forwarded is calculated using following 3 cases:

If C is a member of SA: The next hop node is AA(DC+1, D).

If C is a member of SD: The next hop node is AA(DC-1, C).

Otherwise, the next hop node is AA(DC-1, C)

Where SA = set of ascendants

SD = set of Descendants

D = Destination node address

C = current node address

AA(D, k) is the address of the ascendant node of depth D of the node k

DC = Depth of the current node

The steps followed by this protocol are as follows:

1) When a packet arrives at the current node C, it checks whether the packet is destined for itself. If so, then it delivers the packet to its upper layer. If not, it checks whether destination node is a member of SA, if so the next hop is AA(DC+1,D). If not, it checks whether it is a member of SD, if so the next hop is AA(DC-1,D). If not, it continues with the next step.
2) C broadcasts Hello messages in its Personal Operating Space to get information about A_k and D_k, where A_k is the address of node k and D_k is the depth of node k. It checks whether D is a member of SA_k, if so it forwards the packet to D. If not, it checks whether D is a member of descendant of SA_k, if so it forwards the packet to one having maximum depth. If not, it checks whether D is a ascendant of SA_k, if so it chose the node having minimum depth and forwards the packet to it. Otherwise, it continues with step 3.
3) C calculates all the sibling node of D and checks whether it is member of SA_k, if so it forwards the frame to that sibling. If not the next hop is calculated as AA(DC-1,C)

4.5. Dymo Low (Dynamic MANET On Demand for 6LoWPAN Routing):

The DYMOlow protocol provides an effective and simple to implement routing protocol based on AODV.DYMO performs route discovery and maintenance by using RREQ, RREP and RERR messages. It operates on top of IP layer not on the link layer. DYMO protocol cannot be applied directly in 6LoWPAN routing due to its increased memory and power consumption. DYMOLow works in the adaptation layer. It reaches all the nest hop neighbours by broadcasting RREQ messages. It limits the size of RREQ to IEEE 802.15.4 frame size so that it avoids fragmentation. The intended node replies with RREP message. It uses the link quality information to find the best route. It does not use the Hello message instead it uses link layer facility like acknowledgement to get information about its neighbour nodes.

4.6. Extended Hierarchical routing:

During the time of node failure hierarchical routing does not provide path recovery. Extended hierarchical routing provides a path recovery mechanism for 6LoWPANs. This routing protocol adds the Neighbour Replace Parent (NRP) and the Neighbour Added Child (NAC) entry to an existing routing table as a part of path recovery mechanism. NRP does not point to the parent node, but it points to the upstream node to which the packet is delivered. NAC points to the child of the new parent node. For example, suppose node a is down as shown in the figure 4.2.

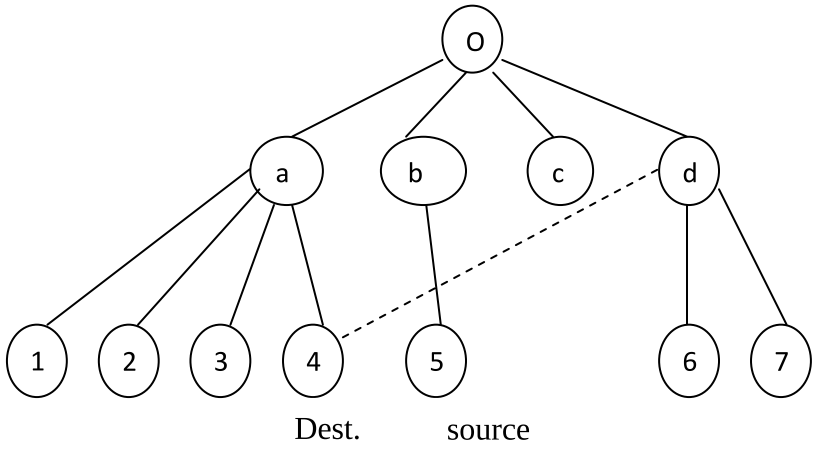

Fig. 4.2 Extended Hierarchical Routing

Now, downstream node 1 cannot transmit packets to the upstream nodes through node a. Here node d is assigned as the NRP of node 4. So node 4, when it does not receive reply from its parent node, assigns a new parent node to node d. After the child node's NRP is set to new parent node and new parent node's NAC is set to the child, packet delivery occurs through NAC and NRP.

4.7. Enhanced Location Based Routing Protocol (ELBPR):

This protocol uses both link quality and the distance between nodes as the routing metric. In LOAD, due to the repeated broadcast of Route Request messages (RREQ) during route discovery process, energy consumption increases and also when there is a link failure, route has to be established again as there is only one source. But ELBPR reduces this network overhead as there exists more than one route to the sink. The next best path will be found by the product of LQI (Link Quality) and distance between the nodes (D).

ER (Edge Router) broadcasts its location information in the network. Source node sends RREQ after sensing data. Only nearby LERs (Local Edge Router) that listens to the RREQ replies by unicast RREP message. Using the information sent by LERs, source node constructs neighbour routing table. Depending on maximum distance between LERs and LQI information, the best LER is chosen. Each node maintains a routing table and a neighbour table. Routing table contains location information of ER, address of ER, source address and source location. Neighbour table consists of location of LERs, their address and LQI using which the best LER is chosen.

4.8. MLOAD (Multipath 6LoWPAN Ad-Hoc on demand Distance Vector Routing):

LOAD repeatedly broadcasts RREQ messages during route discovery phase. MLOAD reduces this network overhead by using multiple alternative paths. During route discovery phase it finds multiple paths and when one main route fails it uses the best alternative path for the transmission of data. It broadcasts RREQ messages during route discovery phase and when an intended node receives the RREQ message it replies with RREP message. This protocol also reduces the power consumption comparatively.

5. Comparison of different routing protocols:

Routing protocols described above are compared depending many routing metrics such as energy consumption, memory usage, scalability, mobility, local repair etc.

Energy consumption: all the routing protocols described above consume less energy. MLOAD and ELBPR consume comparatively less energy to LOAD.

Scalability: Hi LoW, Extended Hi Low, Improved Hi Low and ELBPR are highly scalable when compared to other routing protocols.

Hello message: Hello messages are used Hi Low and Extended Hi-Low, S-AODV and Improved Hi-Low for neighbour discovery.

Memory usage: memory usage in LOAD, S-AODV, Improved Hi-Low, MLOAD and DYMO-Low are little high when compared to other routing protocols described.

Mobility: Hi-Low, extended Hi-Low, improved Hi-Low and SAODV are useful in static networks; where as the rest of the protocols described above are used in dynamic networks.

Routing delay: routing delay is low in all the protocols except DYMO-Low.

Location information: only ELBPR uses the location information for routing.

Type of routing: only S-AODV and LOAD use adaptation layer for routing. So S-AODV and LOAD are mesh under routing. The rest of the routing protocols are route over routing protocols.

5. CONCLUSION:

A survey has been done on 6LoWPAN routing protocols. This paper describes routing mechanism in 6LoWPAN, routing requirements, its parameters and its types. It also explains various routing protocols such as LOAD, S-AODV, DYMOLow, HiLow, improved HiLow, Extended HiLow , M-AODV and ELBPR. In the end comparison has been made between these protocols. HiLow requires less memory, provides scalability. DYMOLow does not use hello messages thus reducing energy consumption. But it has higher routing delay. S-AODV reduces power consumption and provides network life time extension. Improved HiLow and Extended HiLow provides are more efficient than HiLow. ELBPR overcomes the disadvantages of LOAD and uses location information to find the best route. So, according to the requirements of 6LoWPANs, appropriate routing protocols are chosen that performs well in the established environment.

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