BEIOX: The BATMAN Enabled Internet of X

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ABSTRACT
It is anticipated that by 2020 as many as 20 to 50 billion devices will be connected to the Internet. To enable this connectivity IPv6 has been proposed as the only possible variant of IP communication protocol to provide addressing and routing to such a large number of devices. On the other hand enterprises have been reluctant to switch to IPv6 being incompatible with existing IPv4. Similarly most of the end-users and households are least determined to adopt IPv6 for their personal devices. This justifies the need for a communication and routing protocol that is pre-installed on all embedded devices and does not require any configuration by the end-users for transparent connectivity to the Internet. We propose the use of a variant of Better Approach To Mobile Adhoc Networking protocol called BATMAN Low Energy (BATMAN-LE) for use in various IoT scenarios due to its availability, practicality and ease of use.

Keywords
BATMAN, BATMAN Low energy, IoX, BEIOX, Mesh Networking.

1. INTRODUCTION
Internet of Things(IoT) comes with a vision of smart living from smart homes to smart buildings; where devices are intercommunicating without human involvement.

[1] describes IoT environment in which devices communicate with other devices at peer level, where smart phones act as gateways over Bluetooth or Wi-Fi technologies, relieving people from monitoring these devices individually yet providing them with ability to have high level control of the environment or control system.

Keeping in view the number of devices that will be connecting to the Internet under IoT paradigm, almost all of the proposed solutions for IoT rely on IPv6 as the communication protocol to allow addressing and connectivity for millions of devices.

Although it was feasible to use IPv6 on devices that are configured by the skilled network administrators but it is quite difficult for the ordinary users to configure them for Internet connectivity. IoX (Figure:1) changes the scenario entirely where the end-users will be adding "things" to their environment that will connect autonomously without the need of any user configurations to various walks of life.

Furthermore, it has been more than 18 years since IPv6 is introduced but still not being widely deployed. Mainly due to the following reasons highlighted by the critics:

1. The most critical reason of failure is the lack of backward compatibility with IPv4.The transition from IPv4 to IPv6 portrays a complete transformation in the network infrastructure especially the core network having significant costs in terms of time and money.
2. The lack of understanding and steep learning curve for IPv6 concepts by the end-users is another reason why mainstream service providers are reluctant to shift to IPv6 for the end-devices. It is reported that in Australia, only one ISP offers IPv6 by default for new connections and none of the mobile carriers offers it.
3. Network Address Translation (NAT) and Port Address Translation (PAT) solved the problem of translating traffic from multiple devices on private networks to and from the Internet.
4. There are many legacy devices that cannot be upgraded to IPv6 or dual stack configuration.
5. There is an inherent resistance to change unless it is inevitable, which will allow more IPv4 based deployments of IoT devices in near future as compared to IPv6.

This poses a steep challenge for the researchers as how to enable these devices to connect to the Internet without requiring any configuration. Moreover most of the time these devices will be requiring connectivity with their neighboring devices even when Internet is not accessible Thus IPv6 based communication does not fit into the IoT scenario for end-user devices.

To cater for the current as well as future needs of these IoT devices, a robust communication and routing protocol is required that should be natively available in all embedded devices (mostly running Linux base firmware) and that could scale up without being effected by the size of the network as it grows larger.

BATMAN-adv is one such protocol that has been adopted by the Linux community to be eligible to become part of the Linux kernel since its version (2.6.38). Ubiquitous availability of BATMAN-adv in Linux kernel makes it a strong contender for use in IoX.

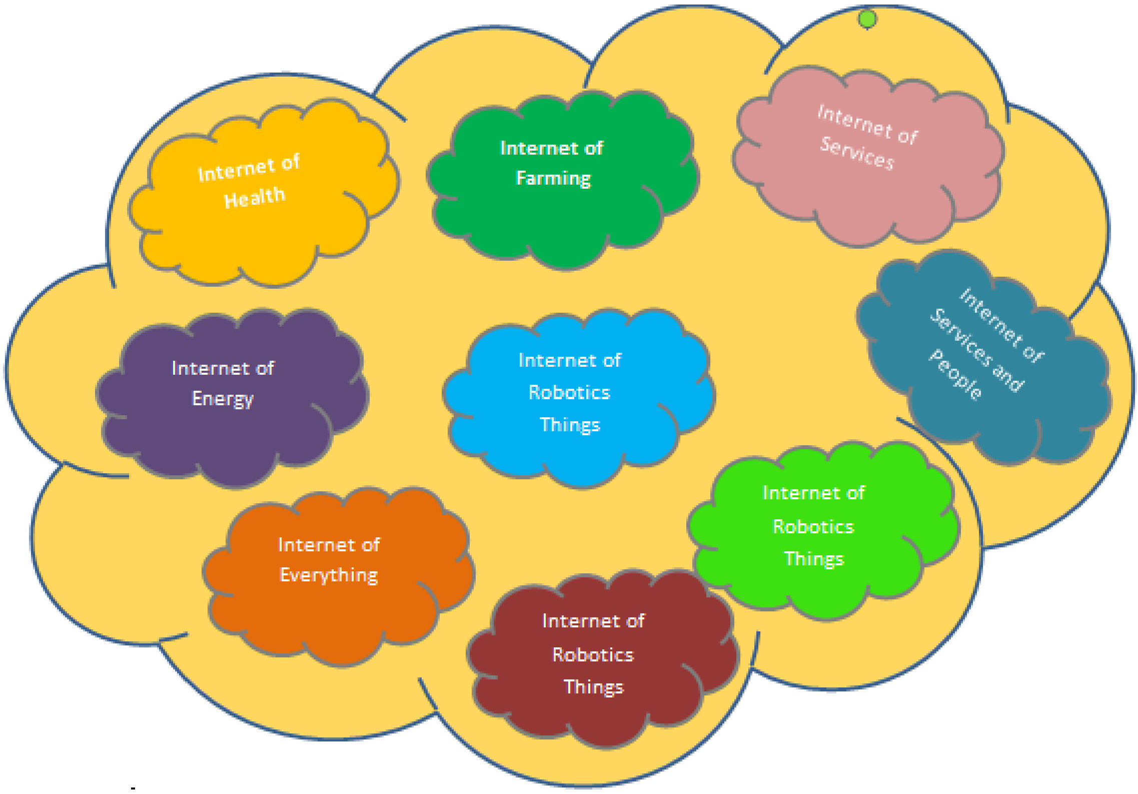


Figure 1 Internet of X (inspired from [1])

The BATMAN-adv not only allows transparent communication between neighboring nodes without any configuration requirements, it also remains transparent for the higher layer protocols without hampering their functionality. Thus all layer 3 and higher protocols will still be able to work on top of BATMAN-adv as they used to do on standard TCP/IP stack.

Since by design, the IoT devices have to conserve energy to remain consistently operational for many years without any user intervention, we propose a low energy variant of BATMAN-adv called BATMAN-LE for end-users devices in various IoT scenarios due to its availability, practicality and ease of use.

The proposed modification is based on a special originator message (TOGM) which indicates that the originator node is going into sleep mode. The detail is further discussed under section 5. Our results demonstrate that the proposed modification not only increases the life of network node but also increases the packet delivery ratio to 100%.

In this paper, Section 2 covers the related work done in the field of low power routing. Section 3 explains the attributes of our proposed IoX protocol stack. Section 4 describes the BATMAN routing protocol. Section 5 puts forward the algorithms of BATMAN-LE. In Section 6 we discuss the expected results of BATMAN-LE. Finally section 7 concludes this paper and paves possible paths for future research.

2. RELATED WORK

The protocols proposed for routing in IoT are RPL CORPL & CARP. Mostly used protocol is RPL. Routing Protocol for Low Power and Lossy Networks (RPL) is an IPv6 routing protocol [3], optimized and designed by IETF over low power and lossy networks (ROLL) [4]. RPL is a dynamic routing protocol aimed for source-sink communication. RPL chooses best path for packet transmission having best routing metrics.

Other than RPL several protocols were introduced for networks having power and energy constraints. These protocols were designed in accordance with the requirements of LLNs to propose a method for efficient routing. Low-energy adaptive clustering hierarchy (LEACH) was a TDMA based MAC protocol proposed in 2000 in [5]. It proposes an idea of random selection of cluster head.

Similarly another approach puts forward an idea of energy aware routing, instead of choosing one path for routing all the time, it chooses a set of good paths and then chooses best of them [6]. The use of a probabilistic forwarding mechanism to send traffic through different routes with the same objective to avoid excessive energy consumption was also proposed [7].

Later with the introduction of adaption protocols for routing layer such as 6LoWPAN, other protocols were introduced as mentioned in [8] i.e. 6LoWPAN Ad-Hoc On demand Distance Vector Routing (LOAD) [9] and Sink Routing Table over AODV (S-AODV) [10]. There is also a 6LoWPAN adaptation of Dynamic MANET On-demand (DYMO) [11].

3. PROPOSED IOX PROTOCOL STACK

For IoX we need a tremendous infrastructure of inter and intra-networks, having capability of resolving different peculiarities of the system. Literature [12] deliberates critical features of IoT environment that must be considered while selecting the routing algorithm. The critical features are Low-power & lossy radio links, Energy harvest nodes, Multi-hop mesh technologies and frequent topology changes due to mobility.

The above constraints results in different challenges like addressing, multicasting, mesh topologies and bandwidth for routing in IoT [13]. For deployment scenarios of IoX it is anticipated that millions of IoT devices will be the consumer devices which cannot be configured without human intervention.

Our BATMAN enabled proposed protocol stack contributes following advantages over the standard IoT over TCP/IP stack, which further augments strength to our IoX model.

- We can run whatever we want to above BATMAN-adv. e.g. IPv4, IPv6, IPX instead of being limited to any one of them.
- BATMAN works efficiently with all available wireless Technologies such as Bluetooth, ZigBee and Wi-Fi (Figure 3).
- It requires no complex configurations allowing the end-users with plug and play connectivity whenever a new device is introduced in their LAN.
- BATMAN despite of being layer 2 protocol qualifies for routing whereby nodes can participate in a mesh without having IPs.
- Its performance is not hampered with the increase in number of nodes.
- Optimization of the data flows through the mesh.
- It follows a ranking procedure [14] to determine the succeeding hops, instead of finding the complete route.
- It facilitates integration of non-mesh clients.
- It offers bidirectional data flow, which in case of IoX plays a vital role in acquiring data even from sensors.

The BATMAN-adv kernel module has been a part of the official Linux kernel since 2.6.38 version; kernel level programs are always more reliable and fast as compared to user level programs. Moreover most IoT devices are Linux/Unix based. The features of BATMAN-adv are best suited in IoX scenarios except for the power consumption problem. Therefore, we propose its enhancement called BATMAN-LE (BATMAN Low Energy), that can be used in resource constrained environments. Figure 3 describes the proposed protocol stack; showing how BATMAN-LE works with three commonly used wireless technologies i.e. Bluetooth low energy, ZigBee and Wi-Fi. We extend this protocol stack specifically for end-users so they can experience plug and play connectivity.

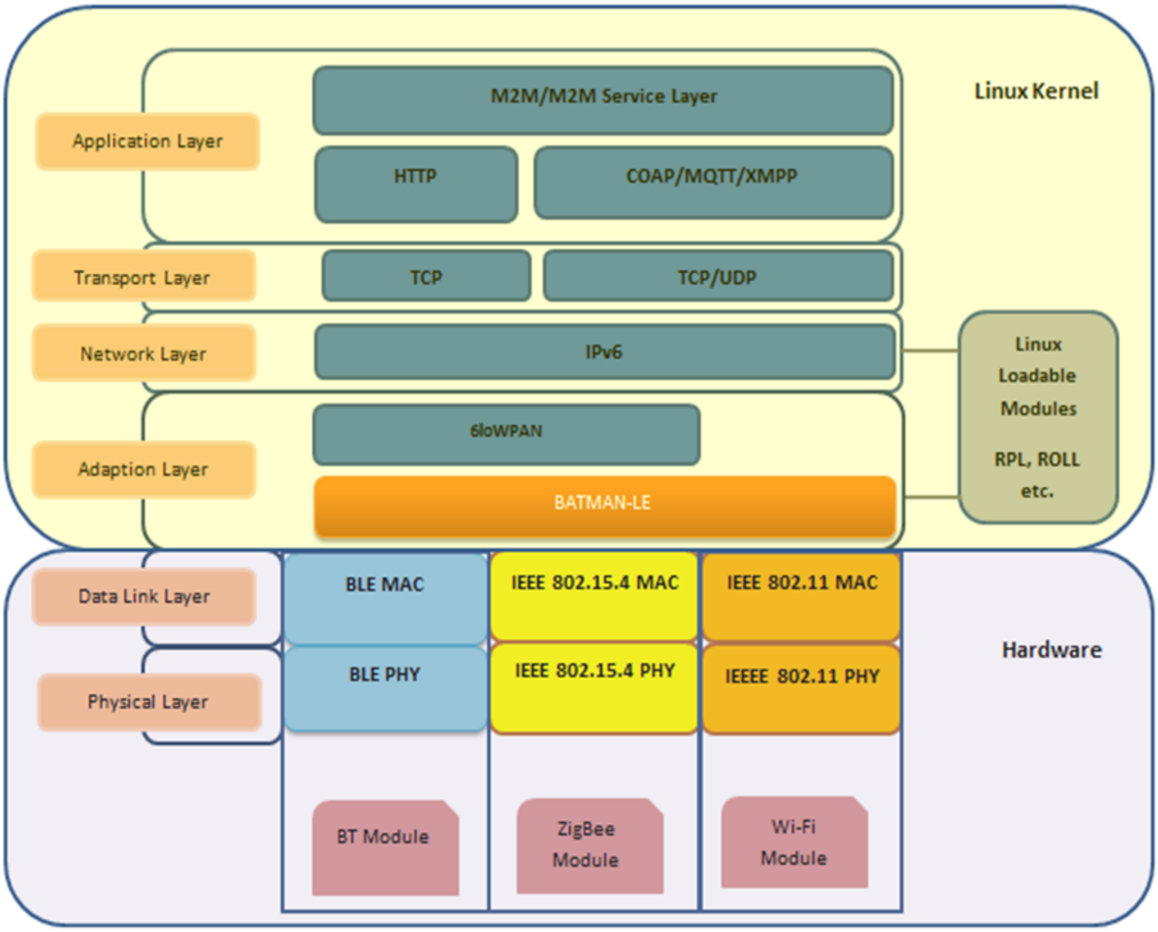


Figure 2 Proposed IoX Protocol Stack

4. B.A.T.M.A.N

BATMAN has been elicited as a biologically inspired protocol based on distance vector routing. Empirically, it possesses the proactive routing approach; in such network every node maintains one or more routing tables representing entire topology of the network [15]. To maintain up-to-date routing information throughout the network, these tables are automatically updated.

The novelty of BATMAN resides in the fact that routing knowledge is made decentralized i.e. no single node maintains routing tables for entire network. Such routing schemes are best suitable for low CPU consumption therefore with less battery consumption for each node, making it an ideal candidate for routing in IoT.

The BATMAN's objective is to maximize the probability of delivering messages. It has been evolved during previous subsequent years, engendering two branches, one as batmand and other as batman-adv. The batmand operates on layer 3 and it requires IP addresses while the batman-adv qualifies as layer 2 routing protocol that requires MAC addresses for routing. In batman-adv, protocols above layer 2 are not aware of the multi hop nature of network, while in batmand, protocols are well aware of the network hops. We have implemented BATMAN-adv (IV) for our test bed.

The protocol operation/execution proceeds as follows:

- Each node broadcasts Originator Messages (OGMs) to every other link local neighbor, to make them aware of their presence. OGMs (BATMAN packets) are considered as hello messages in the network to announce their presence in network and they also measure the quality of routes.
- These OGMs are then rebroadcasted from link local neighbors to the next according to BATMAN forwarding rule. The network is saturated with OGMs until all nodes have received OGMs for once or the TTL (Time to Live) has expired. The number of OGM messages received from a node are used to estimate the link transmit quality (TQ) [16].
- To be able to find the best route to a particular end node, BATMAN counts the OGM messages received from each node in the network and logs as which link local neighbor relayed the message [17].

TCP/UDP port 4305 is assigned by IANA to BATMAN having five types of packets (ICMP, Unicast Packet, Fragmented Unicast Packet, Broadcast packet & Visualization packets) as mentioned in [18].

Each OGM message comprises of different fields as depicted in Figure 3.

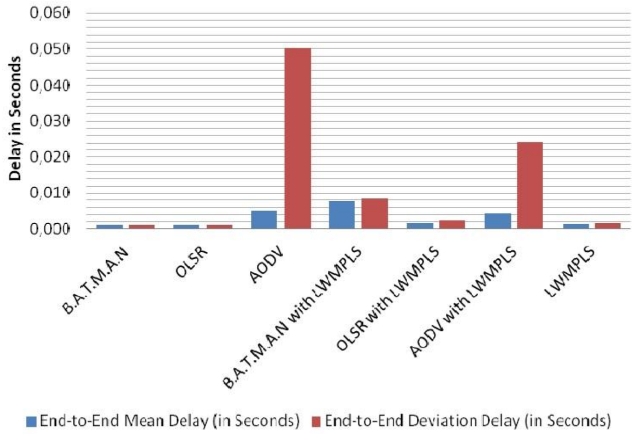
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Packet Type  |    Version    |      TTL      |   Alignment   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Interval                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Originator Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Originator Address       |     Flags     | Gateway Flags |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      TQ       |TT Num Changes |     TT VN     |    TT CRC     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3 OGM Message Format (adapted from [17])

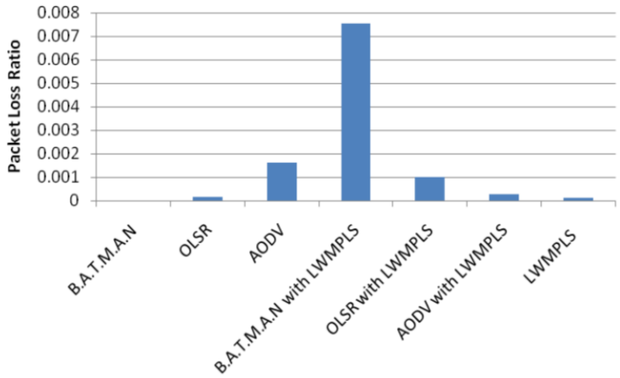
If in the originator address the receiving node finds its own address it means it is a direct neighbor and If the sender address is same as receiving node address i.e.it is already processed and will be dropped. The originator of the OGM is determined; if not available it is created in the table. The ranking of the originator of the OGM is updated. The TQ and TTL fields in the OGM are updated and the OGM is broadcasted again [19].

BATMAN's performance is exceptional as compared to all its competitive protocols. As Arda Yagci et al. in [21] while comparing different routing protocols for Wi-Fi scenarios quoted that BATMAN is a stimulating protocol for WMNs because of its stable routes, minimal overhead and vigorous operation under variable link states.

BATMAN outperformed other protocols like OSLR, AODV. As shown in Figure 4, BATMAN has very low end to end delay and has greater packet delivery ratio.



(a)



(b)

Figure 4(a&b) End to End delay and packet delivery ratio (source:[21])

5. B.A.T.M.A.N LOW ENERGY

BATMAN Low Energy (BATMAN-LE) modifies BATMAN protocol for constrained environments encountered in IoT. We previously proposed BATMAN for IoX scenarios; subsequently we extrapolate our idea as low energy version of BATMAN. We present an algorithm for traditional BATMAN to make it able to store and forward, and to save power for constrained environments. BATMAN-LE advocates itself as an adequate contemporary candidate for resource-constrained LLNs as well as large-scale mesh network routing capabilities.

BATMAN-LE is similar to BATMAN except in the point where nodes can be put to sleep for a stipulated time interval while remaining the part of the network; hence making it a best choice for IoX. In BATMAN-LE we propose an algorithm which employs the BATMAN packets (OGMs) to inform neighbors about the sleep duration of a particular node.

We propose special OGMs for low energy BATMAN as Time originator messages (TOGMs).TOGMs are messages transmitted by any node before it is going to sleep. TOGMs inform the neighbors about the inactive duration of node or the time when it will be again active in the network. TOGMs contain sleeping time information in its TQ field.

BATMAN-LE allows the nodes to sleep for some time during their period of operation. Each node performs three basic functions: sending TOGMs (if the node is going to sleep), receiving TOGMs (updating its table), and scheduling a packet destined for sleeping node as depicted in Figure 5.

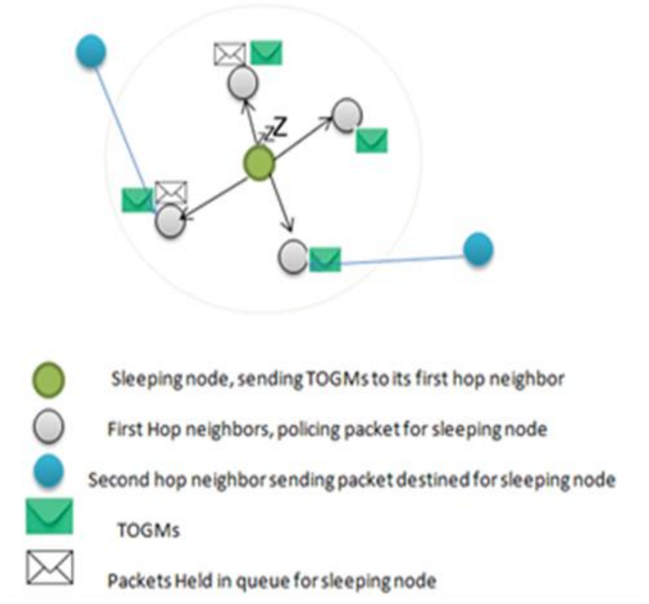


Figure 5 BATMAN-LE Node Functions

To make a node available for polling every time, decision of sleeping duration is made on the basis of preceding and succeeding polling time of the node intending to sleep. Each node calculates its preceding and succeeding polling

time contiguously. As soon as the threshold value (1) is satisfied, it sends OGM with a special TQ value =-0b1 i.e. -1.

Consequently, the node sleeps for Tsd milliseconds (2). Algorithm is defined in Figure 6.

$$(T_{np} - T_p) \geq 1000ms \quad (1)$$

$$(T_{np} - T_p) = T_{sd} \quad (2)$$

The originator sends a special OGM as TOGM to all its first hop neighbors but forwarding TOGMs to second or third hops can cause breakdown of routes in the network because of the path quality (TQ) calculations as shown in equation (3). Figure 7 explains the equation (3).

$$TQa=255;\ TQa'=255\times TQba \quad (3)$$

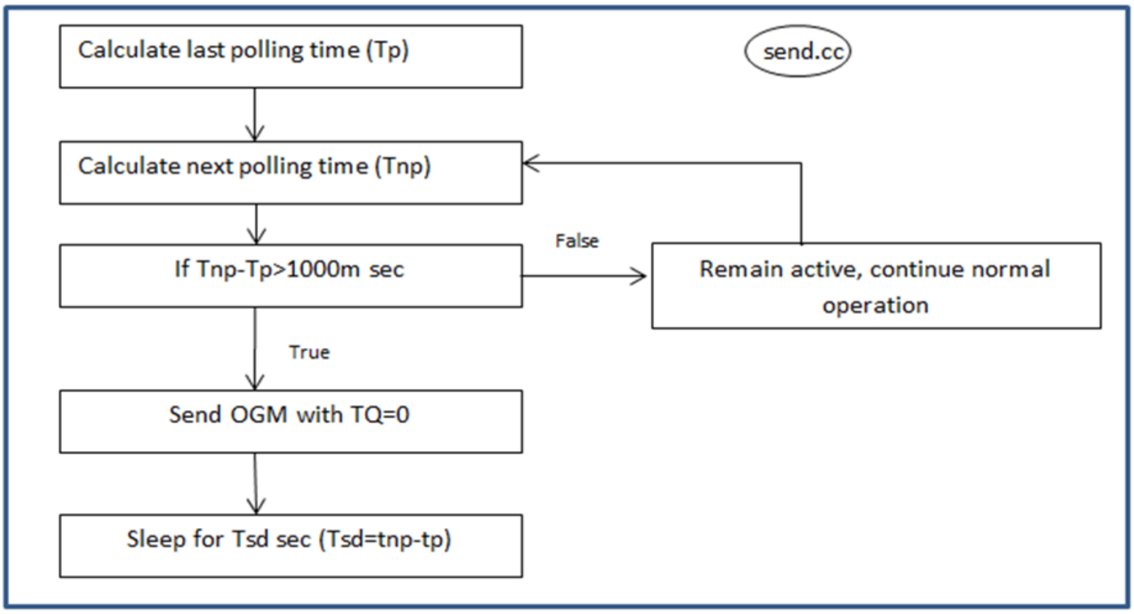


Figure 6 Algorithm for sending TOGMs

The recipient node for TOGM does not forward this TOGM further to its next-hop neighbor nodes, because the negative value of TQ field in TOGM computed by recipient node can't be considered as optimum path quality for further transmission.

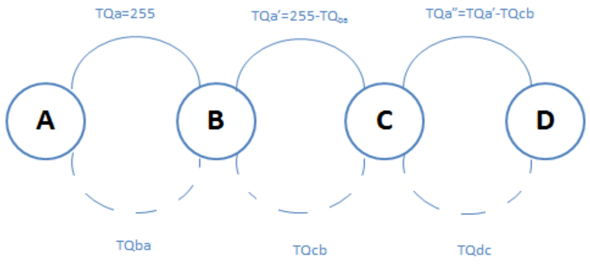


Figure 7 TQ Calculation in OGMs

On reception of TOGM, a recipient node updates its routing table, marking the orig_addr of TOGM as sleeping node and its timer is set to Tsd ms i.e. orig_addr is sleeping for Tsd ms as shown in Figure 8.

As the second-hop neighbors are not aware of the sleeping node, they can send packets with dst_addr = sleep_node. In such cases, the node prior to sleeping node must retain its packet for Tsd ms interval; the packet are resent when sleepy node gets active. A safety time Ty is added along with Tsd to make sure that node is coming back or not. After Tsd ms interval completed by the timer, it waits for Ty ms for this node to resend OGM; if it does not sends OGM, its entry is deleted considering it as dead node i.e., at time Td (drop time) as shown in Eq.(4).

$$Td \geq (Tsd+Ty) \qquad (4)$$

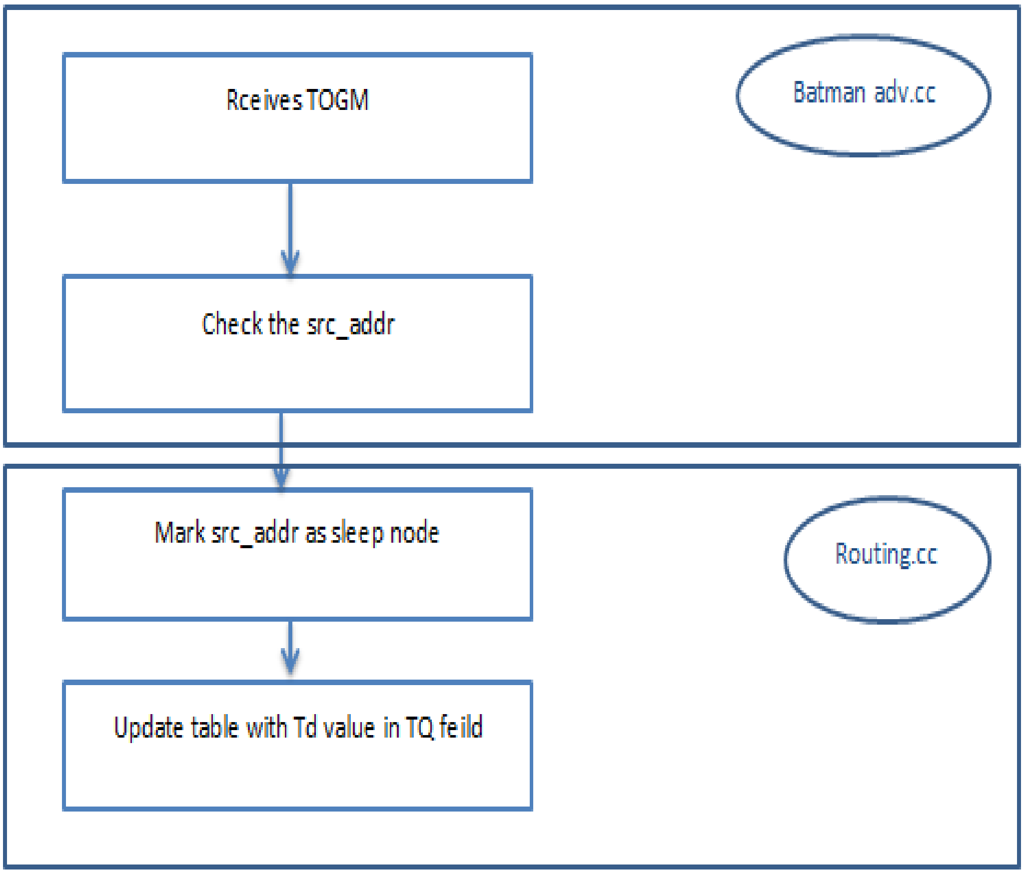


Figure 8 Reception of TOGMs

If the node becomes active within the time limit Td, the packet is sent to the node. Algorithm for Store/Hold and Forward/Send mechanism is narrated in following flow diagram Figure 9.

In case when more than one node have packets for sleeping node, then only one packet is transferred; others are dropped as per routing algorithms.

With the implementation of these algorithms, BATMAN nodes will be able to remain in sleep mode for an adequate time interval to save their energy when they are not in use in network. In Internet of Things paradigm when extensive energy aware routing can be challenge, BATMAN-LE proves to be a robust contender for routing.

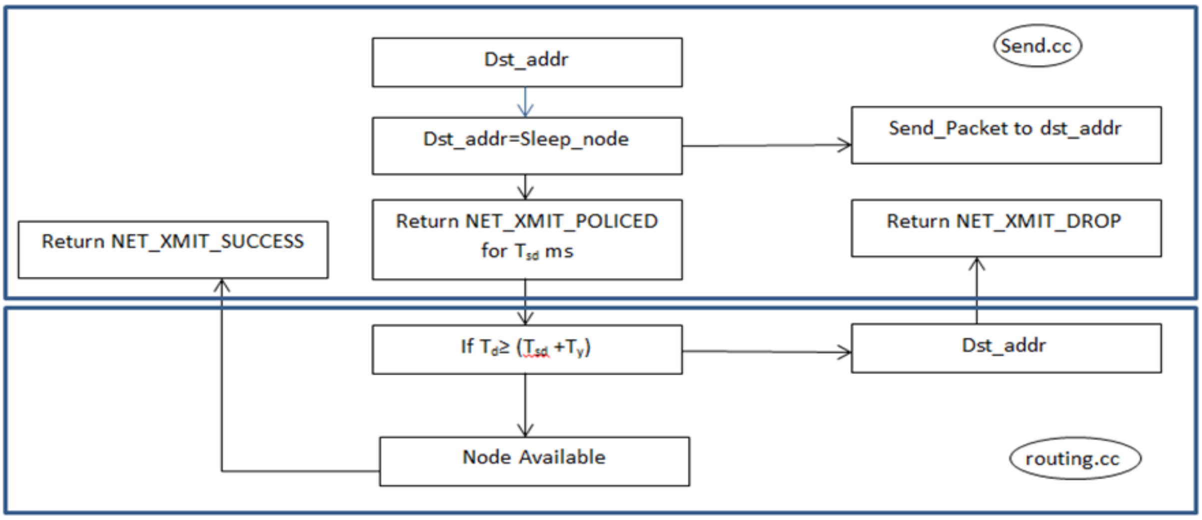


Figure 9 Packet Destined for sleeping Node

6. RESULTS ANALYSIS

The source code[1] of BATMAN modeled by Tobias Hardes et al is implemented in OMNET++ with INET framework.

The changes made in source code are according to the algorithms defined in section 5.

We infer the results on basis of four key performance parameters as Network Life, Latency, Overhead and Delivery Ratio of BATMAN-LE as compared to BATMAN.

Delivery Ratio is the ratio of actual packets delivered to actual packets sent. Considering the Delivery Ratio of BATMAN-LE, we expect it to be on the higher side as compared to BATMAN, due to the fact that packets destined for a node not instantly available in the network, are stored and then re-forwarded to that node when it becomes active (Figure 13).They are dropped only in case when that node does not fulfill the condition as mentioned in equation (IV). The optimistically expected results are modeled in Figure 10.

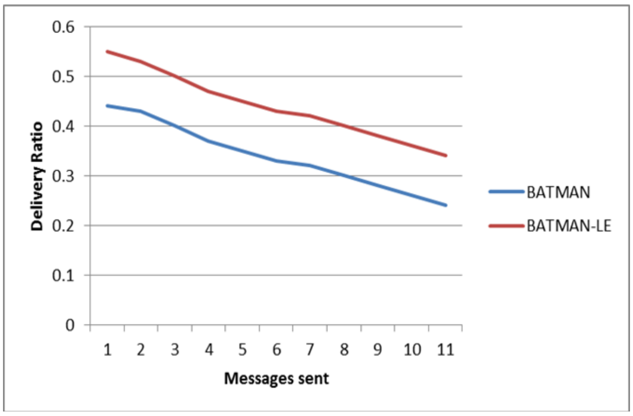


Figure 10 Delivery Ratio of BATMAN-LE

Overhead of BATMAN-LE would be slightly higher than BATMAN, as additional packets are being sent in network. A node sends an extra packet to inform its neighbors about its sleeping duration, it also sends OGM after being active again. The peaks shown in Figure 15 depict the additional packets sent. But such a slight change can be compromised for better delivery ratio. The overhead comparison of BATMAN & BATMAN-LE is shown in Figure 11.

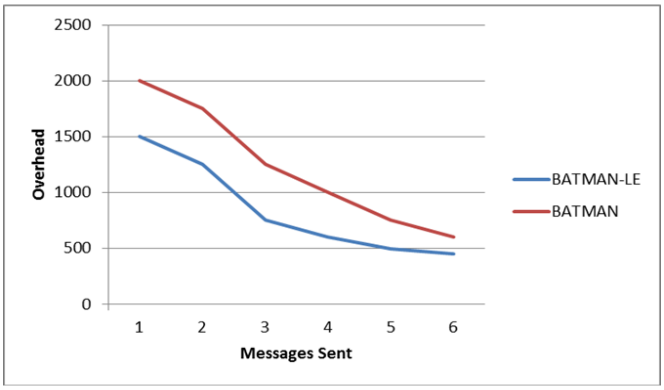


Figure 11 Overhead analysis of BATMAN-LE

Life of networks with BATMAN-LE is higher than that with BATMAN as the nodes in first are adequately allowed to sleep for specific intervals, thus increasing the life of nodes and networks. The expected behavior is shown in Figure12.

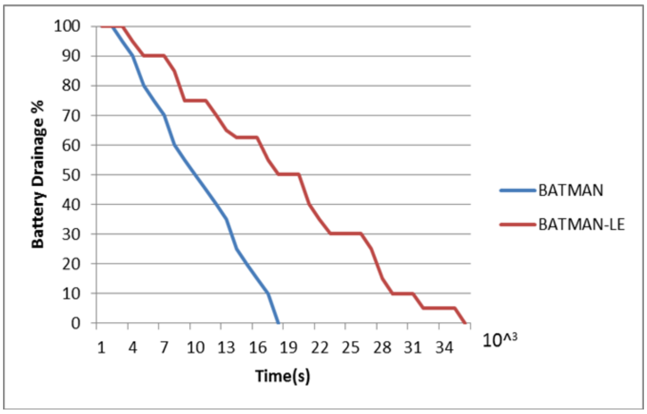


Figure 12 Network Life of BATMAN-LE

It can be clearly seen in the graph that the network life of BATMAN-LE is around (35*10^3)s i.e. approx. 10 hrs.

[1] https://github.com/thardes2/omnetppBatmanADV

Whereas the battery of BATMAN enabled node drained out at (18*10^3)s i.e. approx. 5 hrs. As the BATMAN-LE allows nodes to sleep for certain interval of time, it doubles the life of network.

There may arise some apprehensions for latency during implementation of BATMAN-LE, as the packets are stored for (Tsd+Ty) ms; this can produce nominal delay in overall packet transmission.

Generally, efficiency of BATMAN-LE enabled network remains progressively higher because of the reason that nodes are not promptly in active mode throughout their periods of operation.

7. CONCLUSION

In this paper we propound BATMAN as routing protocol for IoX. Further considering the low power and lossy networks of IoT, we proposed BATMAN-LE as IoT IPv6 routing variant technique. It may pave as a hallmark of cutting-edge routing competitor of IPv6/RPL layer in Wi-Fi enabled IoT paradigm. To avoid modification of Linux kernel, we designed the Low Energy functionality in the user space. In future, we intend to perpetrate akin modifications in Linux kernel.

Further we would like to investigate more on the performance of BTAMAN-LE in various IoX scenarios, with different routing metrics. We would also like to compare its performance with RPL, one of the ubiquitously prevalent routing protocols for IoT.

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