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Variable Length Group Multicasting for IPv6 based Wireless Sensor Network using Protocol Independent Multicast

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Abstract- Internet of Things has the potential to connect sensor network with global network to create smart environment. For global connectivity, IPv6 low power over wireless personal area network stack provides compressed packet header format, addressing and fragmentation within wireless sensor networks. Sensor network has limited energy therefore protocol independent multicast is more feasible approach which avoids self discovery and relies on existing routing protocol. For large networks such as Internet of Things, the scalability and energy efficiency are major issues and protocol independent multicast in fixed memory size limits the network dimensions because of inadequate number of group members. This paper, therefore, proposes a variable length group multicasting with upper layer implementation of protocol independent multicast using Berkeley low-power internet protocol IPv6 stack of TinyOS which consumes 490 bytes of RAM. The results and comparisons in Tossim of TinyOS reveal that our proposed idea is more scalable. When network grows constant 98% packet delivery ratio is achieved having improved energy consumption in comparison with unicast, flooding and branch aggregation multicast.

Keywords: WSN, IPv6 Low power over WPAN, Protocol Independent Multicast, Berkeley Low-power Internet Protocol

1. INTRODUCTION

Wireless sensor network (WSN) is a network technology, where miniature and intelligent sensor nodes communicate with other nodes to present requisite information to the concerned consumers (Akyildiz *et. al.* 2002). In comparison to traditional networks where resources are not an issue, the WSN is low constraint network with respect to memory, radio, battery and processor (Jenifer *et. al.* 2008). WSN was originally initiated by military (Fabian. 2008) and at present it is being used for variety of applications such as habitat monitoring (Tomasz *et. al.* 2010), health monitoring (Youssouf *et. al.* 2008) and animal monitoring (Enkhbold *et. al*. 2008). The theme of WSN is distributed and ad hoc (Yuanli *et. al.* 2006), where sensor nodes correspond with neighboring nodes for network adjacency to pass on information towards the sink or base station. Even with such stringent resources, sensors can sense real time events in the physical world and route the computed results towards the base station (Junguo *et. al*. 2008).

The traditional computer networks use Internet Protocol version 4 publically and privately till February 2011, which is reinstated by its successor Internet Protocol version 6 which provides larger address space and multicasting (Deering and Hinden. 1998). WSN uses serialization and localization techniques for node identity thus introduction of IP based addressing scheme endow a gateway connectivity of sensor networks to global networks. Since IP based addressing scheme is emerging among sensor network research communities for global connectivity (Paulo and Joel. 2010), therefore, different IP techniques are being designed for node uniqueness (Jonathan and David. 2008, Luis *et. al.* 2011) and Internet of Things (Luigi *et. al.* 2010) is the best example of IP based implemented sensor network connected with global network.

In early stages of WSN, unicast (Patros *et. al.* 2013) and broadcast were used for network communication but both techniques lack energy conservation which is the most important issue in WSN. Multicasting, therefore, provides a technique of communication within a specified group to incorporate for certain event or query and hence, is more feasible approach for resource constrained nature of WSN (Imed and Ahmed. 2009). Although, variety of multicast techniques is present in the literature for WSN and they are dedicated to memory constraints (Sheth *et. al.* 2003), energy constraints (Ali *et. al*. 2011), demand based (Sule *et. al.* 2014) and routing constraints (Shaik *et. al*. 2016) but all of them are non IP based techniques.

IPv6 based protocol independent multicast (PIM) in WSN uses fixed memory size for multicasting which

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limits the network scalability and efficiency due to limited number of group members especially in large networks (Alan and Qi. 2011). Furthermore, in fixed size memory, it is not possible for a new node to join the existing group if memory is already occupied by nodes. Keeping in view the dynamic nature of WSN, variable memory provides scalability and energy efficiency in large networks. In order to cope with the mentioned problem a variable length memory is adopted to address scalability and energy efficiency so that multicast group can grow easily. This proposed model scaled better and consumed less energy in comparison with unicast, flooding and branch aggregation multicast.

The rest of paper is structured as follows. In section 2 the prior research regarding multicast and protocol independence are elaborated with their limitations. In section 3, implementation, design, and experiments are discussed with respect to algorithm and obtained results for scalability and energy efficiency. In section 4, paper is concluded.

2. IMPLEMENTATION

The multicast approach in this paper concentrates on PIM technique using Source-Specific Mode (SSM) variant which is the successor of Internet Standard Multicast (ISM) model and therefore, a good approach for IP based networks. The SSM, as reflected in *RFC 3569*, has no *Rendezvous point*, cross delivery traffic and inter-host coordination which make it easier to implement and troubleshoot. It assumes one source for tree construction which is secure and scalable approach. It provides a network layer service with source (S) and destination (G) IP address. The datagram adopts source group (S,G) channels during transmission and receiver can join by subscribing to the same channel. The assigned range for SSM in IPv6 is FF3x::/96 as defined by Internet Engineering Task Force (IETF) in *RFC 4607*.

SSM is wired network protocol and its implementation in WSN is an issue. Therefore, an edge router is recommended within WSN to play a key role for multicast tree construction, subscription and address allocation. The edge router may be a super node that have stronger resources then ordinary node.

Design

Designing WSN is always been challenging because of stringent resources. Therefore, this model is carefully designed using variable length memory for group multicasting keeping in view of energy cost and scalability. The nodes are deployed randomly in distributed manner rather than grid due to its efficient energy consumption and scalability (Monica and Ajay. 2010). WSN depends upon the requirement of the application therefore query based application is preferred over event based because the network is engaged whenever required. The same approach gives improved network life however event based query is also supported in this proposed model.

Simulation

TinyOS 2.1.2 installation is carried out in Ubuntu 14.04.2. For visualization and graphical analysis TOSSIM, a discrete event simulator, is configured which has the capability to maintain sorted queue of events. MViz and JTOSSIM are used for debugging in order to monitor node activities and their response during multicasting.

BLIP, a 6LoWPAN stack is compressed IPv6 packets, is an appropriate selection for Internet enabled WSN (Devasena. 2016). BLIP supports IPv6 header compression, packet routing and DHCPv6. By default BLIP directs each node three different addressing during compile time for link-local-1, link-local-2 and global address. To assign three addresses statically in a large network may be problematic, hence dynamic addressing is suggested. The link-local-1 address is assigned when node boot up and send multicast requests to find neighbors while global addressing is allotted by through DHCPv6 server. The packet size of proposed model is comprised of 20-bytes of header and 200-bytes for payload as shown in **(Fig. 4).**

<table>
<tr><td>Dispatch</td><td>Compressed Header</td><td>Context Identifier (CID)</td><td>Hop Limit</td><td>Source Address 64–bit prefix</td><td>Destination Address 64-bit prefix, 64-bit interface Identifier</td><td>Payload</td></tr>
<tr><td colspan="6">20-Bytes Header</td><td>200-Bytes</td></tr>
</table>

Fig. 4. BLIP packet design

Variable Length Memory

For variability, an algorithm 1 is designed to address memory allocation for multicast tree so that it can be efficiently utilized. The main objective is to assign maximum available space for multicast subscription so that the tree can grow large. The same provided a window to scale network for maximum area coverage where any node, if interested, can join or leave the group. However, memory allocation threshold is assigned in order to avoid memory overflow.

Query Design for Multicast Test

The work presented in this research use query based management where scalability and energy

efficiency are major parameters. However, it can also be used with event based management. An efficient query is therefore required to ask a node in multicast tree for data acknowledge which is designed in TinySQL, which is low power query language for WSN, as shown below.

```
SELECT node ID, light/pressure/heat/sound FROM sensor Number
WHERE light/pressure/heat/sound (Condition) EPOCH DURATION
```

Simulation Presets

The simulation is configured for; nodes mobility sets to null, network communication link sets for duplex with 1.2 MB bandwidth, transmission delay is set to 10ms with a range of 100 meters and data packet of 200 bytes is set for transmission. The simulation model is initially configured for 100 nodes in 200 x 200 square meters terrain as illustrated in (**Fig. 5).** The SSM subscription and multicast query is considered as first iteration. Afterwards, additional 100 nodes were added in the network to converge. Once the network is converged, then the interested nodes can send requests for multicast subscription. Finally, the same network is scaled to 1000 nodes in 1500 x 1500 square meters terrain in ten equal iterations as shown in (**Fig. 6)**. The multicast tests are concluded in each iteration and the results showed that the proposed model is scalable and energy efficient which will be discussed later.

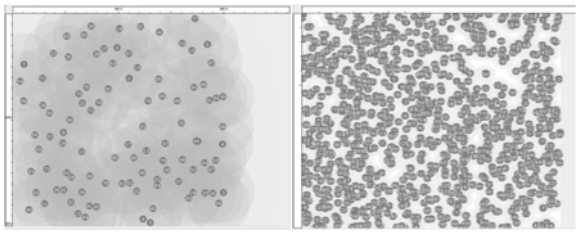


Fig. 5. 100 nodes in 200 x 200 m Fig. 6. 1000 nodes in 1500 x 1500 m

Table 1. Symbols and descriptions

Symbols	Description
N	Node
NI	Node Interested
NNI	Node Not Interested
ER	Edge Router
JN	Join
ACK	Acknowledgement
MSG	Message
RM	Remaining Memory
AM	Available Memory
UM	Used Memory
BN	Boarder Node

Multicast Subscription

Main feature of SSM is that it does not depend on single *Rendezvous point*. It eliminates cross delivery traffic and avoids inter-host coordination. It requires a specified *(S,G)* pair unlike *(*,G)* pair of PIM-SM protocol therefore we are left with two choices:

i) To select a root node manually or
ii) Let the base station/edge router act as a root node.

In this case *ER* is designated as a root node as shown in (**Fig. 7).** The subscription of multicast group is done by SSM where a candidate sends a *JN-MSG* using any available unicast protocol. The same message is received and acknowledged by *JN-ACK* message from source *ER* hence successfully initiating a multicast group for message deliveries. The subscription candidate will continue to send *JN-MSG* unless it gets a *JN-ACK* from *ER.* Once the subscription is done there is no need to send *JN-MSG* from subscriber again. In Fig. 7, the *N3* is a candidate for membership in multicast tree *(S,G).* It sends a *JN-MSG* to *ER* through mediator nodes *5, 4 & 2* saving its next hop address. Valid *JN-MSG* is replied by *JN-ACK-MSG* through unicast. Hence successfully establishing multicast tree membership for *N3*. Algorithm 1 shows the multicast tree construction and network convergence when new nodes are added.

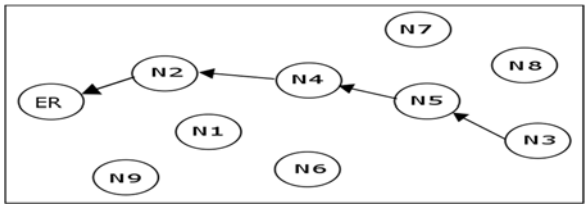


Fig. 7. Node 3 joins ER

Algorithm 1: Multicast Tree and Network Convergence

Procedure: MULTICAST TREE AND NETWORK CONVERGENCE
Input: Node N; Node Interested, NI.
Nodes deployed randomly
Multicast tree construction
If N = NI then
Send JN-MSG to ER
ER ACK
Node become member of Multicast tree
else
NNI
endif
If New node joins **then**
Broadcast identity
ER ACK with ID and Interest MSG
Goto step 2
endif
Query
Data request to BN
BN ACK data
End procedure

Output: Multicast Tree

3. RESULTS AND DISCUSSION

Scalability

WSN requires scalability to cover up network of large area or increase in workload (Swati *et. al.* 2014). Scalability is the capability of network to scale and perform by achieving high ratio of packet delivery. Scalability depends on number of nodes, network range and protocols; therefore, it is an important factor to plan for large network where heavy traffic of packets originates. The scalability can be tested on parameters such as delay, through put, life time, success rate, latency, energy consumption and packet generation rate (Alazzawi and Elkateeb. 2008).

Fixed memory size for multicast group reflects various limitations such as status of new node membership is unknown once memory is occupied and how much the multicast group will grow. Therefore, variable length memory will provide larger multicast memberships and hence, resulting scalability as shown in algorithm 2. Generic Telosb mote have MSP430 8MHz microcontroller with 10kB RAM. TinyOS, BLIP, SSM and this proposed model occupied a total of 11192 bytes in ROM and 490 bytes in RAM which left us a space to scale our model on the grounds of application which depends on end user requests. The remaining memory will be calculated through equation 1.

$$RM = AM - UM \quad (1)$$

Equation (1) reflects that the remaining memory (RM) is the difference between actual memory (AM) and used memory (UM). The multicast tree can grow as far as RM is available. However, 10% of actual memory is reserved as a threshold for data sensing and aggregation as shown in algorithm 2.

Algorithm 2: Scalability and Memory Variability

Procedure: SCALABILITY AND MEMORY VARIABILITY
Input: Available Memory, **AM**; Remaining Memory, **RM**.

Scalability
  End user request from ER to BN
  BN ACK
  ER verify ACK from BN to calculate %PDR
Memory Variability Check
  Check RM
  If (RM >= 10% of AM) then
    Allow new nodes membership
  else
    Reject new membership
  endif
End procedure

Output: Scalability achieved

The results of self-test are collected with respect to percent packet delivery ratio (%PDR) and energy consumption when network nurtures. In simulation, 100 nodes are randomly deployed for multicast group tree construction where *ER* acts as a root node. A total of 6 transmissions are generated to calculate %PDR by targeting nodes at the boundaries (BN) that are far away from *ER* in order to seek network strength. The first iteration gives a value of 98.8% PDR. For second iteration, the network was scaled to 200 nodes and after successful convergence 6 transmissions are generated which gives 98.29% success rate. A total of ten iterations are concluded and on final iteration, the proposed model scaled efficiently by achieving an average PDR of 98.39% as shown in **(Fig. 8).**

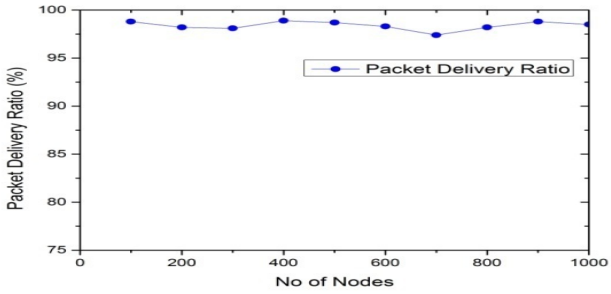


Fig. 8. Packet Delivery Ratio % in 10 equal iterations (Avg PDR = 98.39 %)

The comparison was extended to unicast, flooding and BAM as shown in **Fig. 9.** The results revealed that this model is more scalable with respect to unicast and BAM when network grows. Unicast is the core routing protocol for any network convergence which follow hop by hop procedure and therefore require high resources in large networks. Unicast scaled in simulation tests with a cost of high exploitation of bandwidth, energy and latency. For BAM, the protocol independence is found useful in simulations results which show that PIM is suitable option for any network but M-BAM is more suitable choice than S-BAM when scalability is required however, reduced performance is observed when workload increases. In our simulation results, the flooding protocol exceed better but below 1% because the flooding protocol use replication procedure to every node and it have broadcast nature. The data is replicated at each node and is flooded to every neighbor node without any route discovery by the cost of high bandwidth and energy consumption.

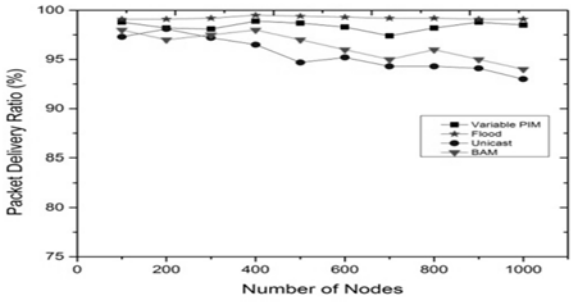


Fig. 9. Packet Delivery ratio %age of Unicast, Flooding, BAM and Variable PIM

Energy Consumption

WSN communications are power hungry and hence, energy is a main problem. Energy consumption depends on physical structure of sensor motes such as transceiver, antenna, routing protocol and scheduling. Efficient operating system and routing protocol can grip transceiver wake and sleep modes while single antenna can be utilized in multiples using virtual multiple input multiple output (MIMO). Multicast has the tendency of limiting transmission packets for any query or event therefore; it reduces the power consumption. For large networks, variable length group gives provision of maximum node membership to cover maximum area. TelosB TPR2400 chipset motes with single antenna are configured in TinyOS using 2AA batteries. The following energy model deliberated our tests as shown in equation 2.

$$E_{TX}=KE_{electronics}+KE_{amplifier}\, d^2 \quad (2)$$

Equation (2) is actually a power control model which target to control the powers during transmissions. However, transmission power always depends upon distance between sender and receiver. The said equation shows that a node energy consumption (E_{TX}) can be calculated for transmitting single bit (K) from one node to another for a square distance (d). The $E_{electronics}$ shows energy of electronics for digital coding, modulation and spreading while $E_{amplifier}$ is the signal strength. The assumption of residual energy 400 µJ is taken for single data transmission, where $E_{electronics}=50nJ/bit$, $E_{amplifier}=100\ pJ/bit/m^2$. The equation and values are same as assumed by the authors in (Noor *et. al*. 2015). Furthermore, two AA of 1.5 volt batteries are taken to calculate initial energy of single node which is evaluated in equation 3.

$$\begin{aligned} \text{Energy (Joule)} &= \text{Power (Watt) x Time (Seconds)} \quad (3)\\ &= 3.0\ (\text{volts}) \times 0.023\ (23\text{mA}) \times 120\ (\text{sec})\\ &= 8.28\ \text{J} \end{aligned}$$

Multicast group members are categorized in two sets as PIM main nodes (P_{mn}) and PIM leaf nodes (P_{ln}). The energy consumption tests concentrates on P_{mn} because they are viable for data transmission from source to destination. A total of 20 data transmissions were conducted in multiples of two minutes. The results were encouraging in comparisons with unicast, flooding and BAM as shown in **(Fig. 10).**

For each *120 seconds*, the node energy consumed by each data transmission is compared with initial energy for a total of *1200 seconds*. Ten transmissions for unicast is completed in first phase and node energy is noted down for each transmission. In second phase,

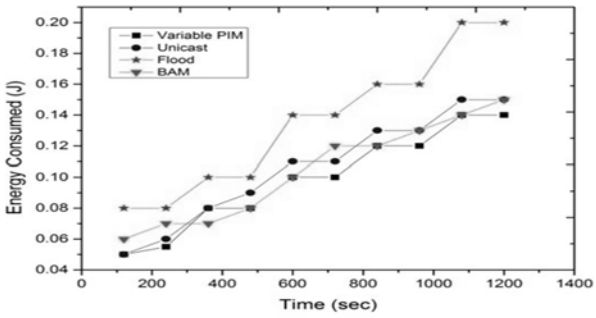


Fig. 10. Overall Energy Consumption

BAM and for third, flooding are taken to calculate energy level of node after each transmission. The concluding energy consumption goes high for all protocols as illustrated in **(Fig. 10)** except for our model with an average of *20%* better life time.

4. CONCLUSION

The Wireless Sensor Network and Internet Protocol are the main requirements for smart sensing and global connectivity. 6LoWPAN and PIM-SSM are viable methods to collect requisite information from WSN. Once fixed size memory is occupied by multicast group then a new node membership is not possible which effect overall network scalability and efficiency. In large networks, energy efficiency and scalability is a significant topic which is addressed in this paper by achieving a packet delivery ratio of *98.39 %* in 10 equal iterations. Our model remains constant from 100 to 1000 nodes in comparison with unicast, flooding and BAM. Also energy consumption was compared with above protocols and the results revealed that our model consumes less energy. Therefore, variable length group multicast using BLIP and SSM are more scalable and energy efficient.

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