Combined Hybrid Routing Algorithm for WPAN

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***Abstract*— Wireless sensor/actuator networks ("sensornets") represents a new computing class consisting of large number of nodes which are often embedded in their distributed operating environments. The emergence of this new computing class raises many system design challenges. One of the major challenges is to develop a very lightweight routing protocol which can run on this low powered, low memory equipped tiny devices. Traditional routing algorithm such as DV, AODV, Link-State, Dijkstra etc requires routing table along with other data structure which is not suitable in the case of sensornets. ZigBee alliance has proposed a routing protocol which works on mathematical formula and consumes less resources but it has limitation on network breadth depth etc. We addressed network depth problem in our paper "Address Borrowing in Wireless Personal Area Network" [1], addressed network breadth problem in our papers "Single Level Address Reorganization In Wireless Personal Area Network" [2] & "Multilevel Address Reorganization Type 2 I N Wireless Personal Area Network"[3]. Similarly we tried to tackle linear network problem in our paper "WPAN Routing Using Huffman Technique"[4]. We have addressed link failure problem of dynamic network in our paper "Multi Channel Personal Area Network (MCPAN) Formation and Routing"[5].Now here in this paper we will discuss about a routing framework which can be applied in any operating space. It uses all the techniques discussed so far in above mentioned papers. In real world almost all the operating space is asymmetric in nature.**

Keywords*— *PAN; Mesh; Address Reorganizing; Routing; WPAN;Tree;Multi Channel;

I. INTRODUCTION

In real world almost all the operating space is asymmetric in nature. In which the devices needs to be distributed in such a way that there will be crowded portion whereas the other portion is less crowded .For example in a college campus the no of devices to be connected will be high in Lab areas, but other area such as cafeteria or passage will require lesser no of devices to be connected. If we think of IT parks the hub room or server room will be crowded. In a factory installation the no of devices to be connected will be high near vital machinery installations. If we take a look at the Elcot IT park we can see that its middle wing is lower than the other two again the left wing is taller than the right wing. We will apply our framework with a similar structure. Here for Simplicity we have shown only a small network which is less than 16 hops. But in actual situation linear portion may span more than 16 hop .

Fig.1. Different workspace

II. OVERVIEW OF TREE ROUTING

Compared to the other kinds of routing, Distance vector Routing, Compact Routing etc. tree routing is simplest as it does not require any Routing table. In tree network topology a central 'root' node is connected to one or more other nodes that are one level lower in the hierarchy similarly these nodes are connected to their child nodes and so on. The hierarchy of the tree is symmetrical, each node in the network having a specific fixed number, f, of nodes connected to it at the next lower level in the hierarchy, the number, f, being referred to as the 'branching factor' of the hierarchical tree.

A. Distributed address assignment

Each router capable device in the network is handed over a sub block of address by its parent. This sub block is calculated based on the following parameters. For a given values for the maximum number of children a parent may have, nwkMaxChildren (Cm), the maximum depth in the network, nwkMaxDepth (Lm), and the maximum number of routers a parent may have as children, nwkMaxRouters (Rm), then Cskip(d), essentially the size of the address sub-block being distributed [18] by each parent at depth, d, is:

$$C_{skip}(d) = \begin{cases} 1 + C_m.(L_m - d - 1), \; If \;\; R_m = 1 \\ \dfrac{1 + C_m - R_m - C_m.R_m^{\,L_m - d - 1}}{1 - R_m}, \; Otherwise \end{cases} \quad (1)$$

Network addresses should be assigned to router-capable child devices using the value of Cskip(d) as an offset. R^{th} Router address at depth D is:

$$A_{R^{th}} = A_{parent} + C_{skip}(d).(R^{th} - 1) + 1 \quad \textbf{(2)}$$

Network addresses to the end devices are assigned using the following equation [18].

$$A_n = A_{Parent} + C_{skip}(D).R_m + n \quad \textbf{(3)}$$

$1 \le n \le Cm - Rm$ *And* A_{parent} *is address of parent*

B. Tree/Hierarchical Routing

If the destination is a descendant of the device, the device shall route the frame to the appropriate child. If the destination is not a descendant, the device shall route the frame to its parent. D is a descendant if following is true:

$$A < D < A + C_{skip}(d-1) \tag{4}$$

For descendent devices the destination is an end device if following equation hold true.

$$D > A + R_m . C_{skip}(d) \tag{5}$$

If it is a child end device then the address N of the next hop device is given by: N=D. **(6)**

Otherwise, the next hop address is given by:

$$N = A + 1 + \left\lfloor \frac{D-(A+1)}{C_{skip}(d)} \right\rfloor \times C_{skip}(d) \tag{7}$$

III. Proposed Combined Hybrid Routing

As we can see tree routing is based on symmetric address distribution it's suitable for symmetric operating space. In this paper we have provided a combined hybrid routing framework which will integrate all algorithms [1, 2, 3, 4, 5].

A. Required data structure

The different PAN structure we have discussed so far are regular, address borrowed, address reorganized, linear and multichannel. Following table describes different network subtypes and the bit format which represents that.

TABLE I: NETWORK TYPE

Network structure Type Value	Meaning
000	Normal PAN
001	Address Borrowed
010	Address re-organized
011	Linear
100	Multichannel

16 bit PAN address will have 3 different sub parts as follows:

TABLE II: ADDRESS FIELD SUBTYPES

Network sub type	Serial no	Address

Network sub type: This field will depend on the no of different subtypes. For our network there are 5 different sub types to represent that we need 3 bits.

Serial No field: The combination of this field and network subtype will uniquely identify a network portion refer **Figure 2**.If in a network there are 3 regular Sub PAN,2 Addressed borrowed sub PAN,5Addressed reorganized sub PAN,3 Multichannel sub PAN. Then the maximum number of any sub type is 5. So this PAN will have 3 bit for serial no field.

Address: This will be the address of the node in the network sub type. This will have rest of the 16 bit that means in the given network 10 bit (16-3-3) will be used for addressing any node within a particular subtype.

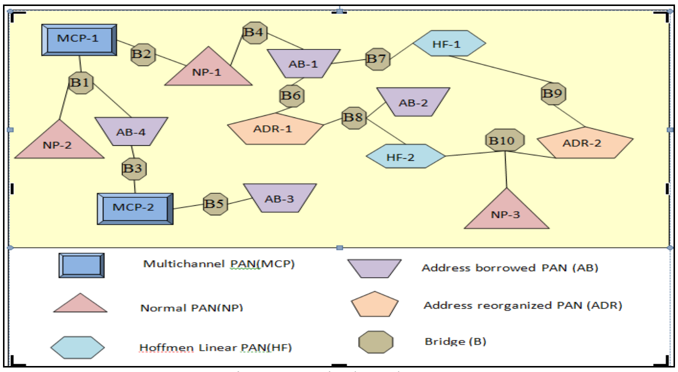

Fig.2. A typical workspace

BFFD (Bridge Full Functional Device) or bridge (**B**) in short these special devices will be capable of transferring data between two heterogeneous PAN constructs and will be situated at the junction.

TABLE III: ADDRESS SUB FIELDS SHOWN IN FIGURE 2

Network sub type	Serial no(Bit)	Address
3 Bit	2 Bit	11 Bit

Each bridge will have multiple addresses 1 for each connecting PAN subtype it belongs to. For example Bridge B1 will have 3 addresses. In a different way B1 will be part of the all 3 PAN subtypes it is directly connected to (MCP-1, AB-4, NP-2). Each Bridge will maintain 1 table called bridge table which will contain all its address and the address of other bridges present inside the network subtype it's connected to.

TABLE IV: BRIDGE TABLE OF B1

Bridge Address	Own Address(0 -yes,1-no)	Next hop address
100_00_00001010000	0	
000_01_01000000000	0	
001_11_00101000000	0	
100_00_00000010010	1	100_00_00100010011
001_11_00101000111	1	001_11_01100000111

Given the above bit format the address sub block available to each of the PAN sub types mentioned in Figure 2 is given in the following table.

TABLE V: ADDRESS RANGE

PAN Subtype	Address range
NP1	000-00-00000000000 to 000-00-11111111111
NP2	000-01-00000000000 to 000-01-11111111111
NP3	000-10-00000000000 to 000-10-11111111111
AB1	001-00-00000000000 to 001-00-11111111111
AB2	001-01-00000000000 to 001-01-11111111111
AB3	001-10-00000000000 to 001-10-11111111111
AB4	001-11-00000000000 to 001-11-11111111111
ADR	010-01-00000000000 to 010-01-11111111111
HF	011-00-00000000000 to 011-00-11111111111
HF	011-01-00000000000 to 011-01-11111111111
MCP1	100-00-00000000000 to 100-00-11111111111
MCP2	100-01-00000000000 to 100-01-11111111111

B. Network formation

For simplicity we have taken 3 network sub types. Let us take the structure of Elcot IT Park and try to apply our framework to form a PAN in it but with a scaled down version for simplicity. As a first step PAN coordinator (solid circle) will scan the whole operating space and generate a MAP of the devices needs to be connected. Following **figure 3** shows a typical device MAP for this operating space.

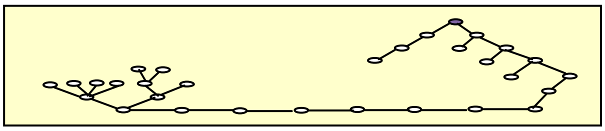

Fig.3. Device MAP with connectivity requirement

The framework will analysis the pattern and decides how many different subtypes are present and what sub type they falls into, In **Figure 4** we have shown the resultant partitioning. The resultant network have 3 sub type Part A, Address reorganized PAN, Part B Linear PAN, Part C Address Borrowed Network. Each sub type will have a node acting as local PAN coordinator marked in solid circle. So there will be originally 1 PAN coordinator (solid circle in PartC) and two pseudo pan coordinators (solid circles in part A and B).

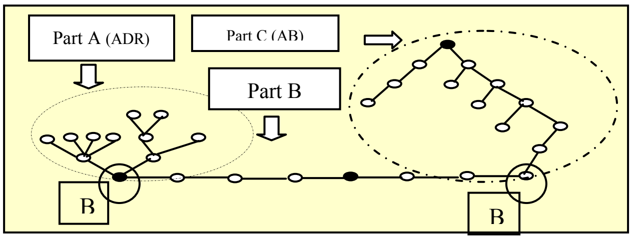

Fig.4. Network sub types

C. Address Allocation

Address will be allocated in a distributed manner each PAN coordinator will take the responsibility of allocating the address within the network sub type. The original PAN coordinator in which our framework will be running will assign address for each PSEUDO PAN coordinator and each Pseudo PAN Coordinator will responsible for allocating the address within its sub net. In the example network there is only 3 different network subtype present so **Network sub type field will be 2 bit long.** There is only 1 network for each subtypes, so **Serial no field will be 1 bit long.** The rest of the 13 bit will be used for address bit.

TABLE VI: ADDRESS RANGE OF FIGURE 4

PAN Subtype	Address range
AB	00-0-0000000000000 to 00-0-1111111111111
HF	01-0-0000000000000 to 01-0-1111111111111
ADR	10-0-0000000000000 to 10-0-1111111111111

Part A PAN Coordinator Address: **10-0-00000000000**
Part B PAN Coordinator Address: **01-0-00000000000**
Part C PAN Coordinator Address: **00-0-00000000000**

Each PAN coordinator will allocate address to its child node using the addressing scheme for that sub type. For example Part A will re-organize its address by 1 level so that it can have 4 nodes connected. Part B will use Hoffman addressing scheme and PART C will use address borrowing scheme.

D. Address Allocation in Part A

As we can see that 13 bits are available for addressing if we select Cm=2 and Rm=2 the maximum length could be 13 but for simplicity in explaining we are assuming that the maximum length (Lm) is 4.Following table shows the values for Cskip in normal PAN

TABLE VII: ACTUAL CSKIP FOR PART A OF FIGURE 4

Depth in the Network	Offset Value [Cskip(d)]
0	15
1	7
2	3
3	1
4	0

Now after applying address reorganization by 1 level the Cskip values will be as follows

TABLE VIII: PSEUDO CSKIP FOR PART A OF FIGURE 4

Name	Value
Actual Cskip(Cskip)	7
Pseudo Cskip(Pcskip)	3
Actual Level(d)	1
Pseudo Level(Pd)	2

If we ignore the most significant 3 bits and consider only the least significant 13 bits then the resultant network with the address distribution is shown below.

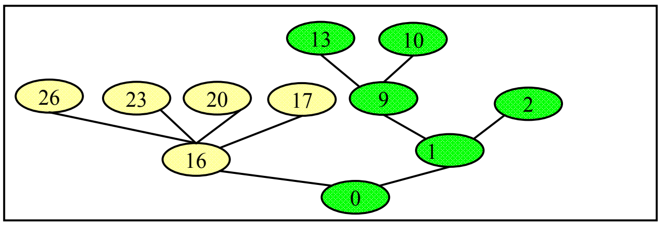

Fig.5. Part A- Address Distribution

Following table gives the actual address of each node after considering the MSB also.

TABLE IX: ADDRESS OF THE NODES

Address Bit	Address in figure 4	Actual Address
10-0-0000000000000	0	32768
10-0-0000000000001	1	32769
10-0-0000000000010	2	32770
10-0-0000000001001	9	32777
10-0-0000000001010	10	32778
10-0-0000000001101	13	32781
10-0-0000000010000	16	32784
10-0-0000000010001	17	32785
10-0-0000000010100	20	32788
10-0-0000000010111	23	32791
10-0-0000000011010	26	32794

E. Address Allocation in Part B

The Solid circle in the middle will act as the PAN coordinator of this network subtype. The doubles circled nodes are the bridges. The values on the link shows the level of the link as all the router node except the PAN Coordinator (Solid circle) has only one child the link level is 0.The left link for PAN coordinator is 0 and the right level is 1.The resultant network with address assignment is shown in **Figure 6.**

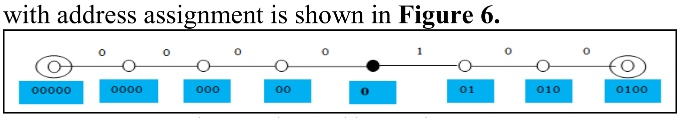

Fig.6. Portion B address assignment

F. Address Allocation in Part C

For simplicity of discussion we have chosen Cm=2, Lm=4, Rm=2 so that address exhausted after 4th level. Figure 7 shows the resulted network with address allocated to it. We can see that even if the address exhausted at node 29 even it has allowed to add more node by borrowing address from node 17. Table 9 gives the actual address of each node.

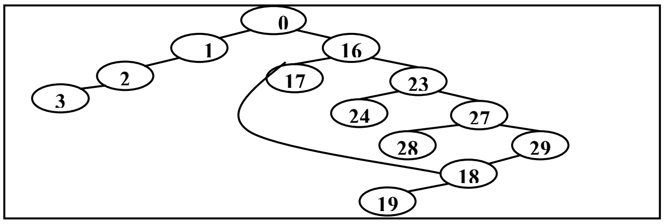

Fig.7. Portion C address assignment

TABLE X: ADDRESS OF THE NODES

Address Bit	Address in figure 4	Actual Address
00-0-0000000000000	0	0
00-0-0000000000001	1	1
00-0-0000000000010	2	2
00-0-0000000000011	3	3
00-0-0000000010000	16	16
00-0-0000000010001	17	17
00-0-0000000010111	23	23
00-0-0000000011000	24	24
00-0-0000000011011	27	27
00-0-0000000011100	28	28
00-0-0000000011101	29	29
00-0-0000000010100	18	18
00-0-0000000010101	19	19

In our sample network we are having two bridges B1 and B2 .B1 is connecting Part A and Part B .Bridge B2 is connecting Part B and Part C. Each bridge will maintain a bridge table following two tables shows the entry for bridge table maintained at each bridge.

TABLE XI: BRIDGE TABLE OF B1

Bridge Address	Own Address(0 -yes,1-no)	Next hop address
10-0-0000000000000	0	
01-0-00000000 00000	0	
00-0-0000000010101	1	01-0-000000000 0000
01-0-000000000 0100	1	01-0-000000000 0000

TABLE XII: BRIDGE TABLE OF B2

Bridge Address	Own Address(0 -yes,1-no)	Next hop address
10-0-0000000000000	1	01-0-0000000000 010
01-0-0000000000000	1	01-0-0000000000 010
00-0-0000000010101	0	
01-0-000000000 0100	0	

G. Routing in Bridged Network

Now let us discuss how routing will be done in reorganized network. Routing within any subnet will follow the routing scheme applicable for that subtype. We will not go through them here.

We will concentrate on inter subtype routing here. If network subtype and serial no of the destination that matches it will forward it to the next node in the route else it will forward the message to all the Bridge present in the subtype by tunneling the message i.e. it will create new message with destination as the Bridge address and the actual message as an payload. Following diagram shows the flow chart of the algorithm

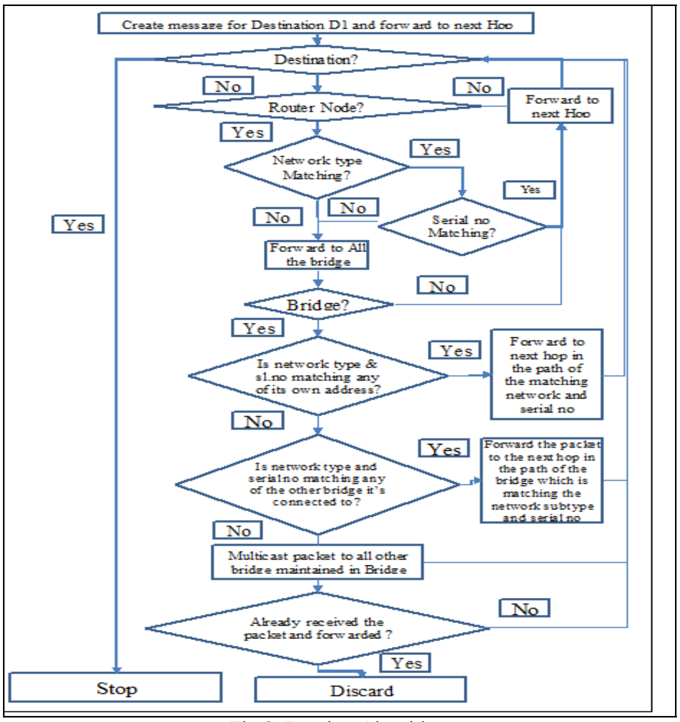

Fig.8. Routing Algorithm

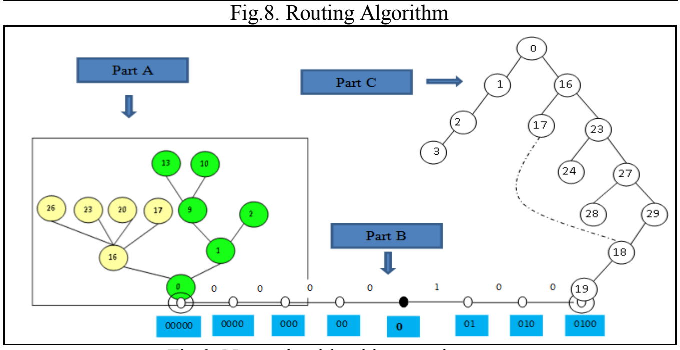

Fig.9. Network with address assignment

Let us now discuss the routing algorithm with an example. Say node 2 of part A sends a message to node 24 of PartC. Node 2 will create a message with destination address as 00-0-0000000011000.i.e. 00-0-24 and forward that to its parent **Node 1(Router)**.Node 1 will match destination address network type and serial no with its own address (10-0-0000000000001) as its not matching it will forward it to the Bridges it's connected to which is node 0 (This is pan coordinator as well).Node 0 will check its bridge table to find out the match in this case Bridge 2 (address 00-0-0000000010101) so it will tunnel the message to B2 via next hop (01-0-000000000 0000) maintained in bridge **table 10**. Bridge B2 on receiving the message will unpack it, check the destination address and forward it to the next hop (node 18) in the path to 00-0-0000000011000.i.e. 00-0-24.After that it will follow normal routing for Address Borrowed network.

IV. Analysis of the Application

Let us now discuss the performance of the framework we will discuss based on the following parameters.

- Memory requirement
- Extra processing overhead.

A. Memory Requirement

Each Bridge in the network need to maintain bridge table with two fields of 16 bit address and 1 flag bit altogether 33 bit. If in the network we have N no of Bridge and K be the no of sub nets and each bridge is connected to P sub nets on an average. Average no of Bridge (Ba) in each sub net is K/N.

TABLE XIII: MEMORY OVERHEAD

Average no of Bridge in each subnet(Ba)	Average No of subnet bridge connected to(P)	No of entry in bridge table	No of Bits required for bridge table
2	2	4	132
3	2	6	198
4	2	8	264
5	2	10	330
2	3	6	198
2	4	8	264

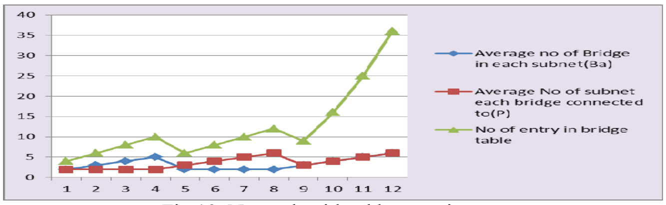

Fig.10. Network with address assignment

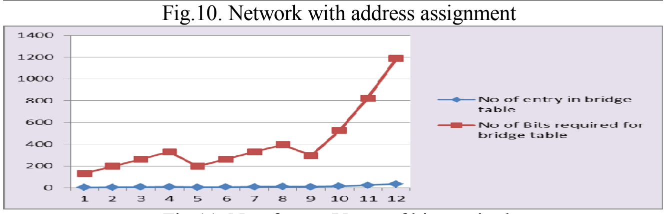

Fig.11. No of entry Vs no of bit required.

B. Processing Overhead

There is no extra overhead for intra subnet routing. Only extra processing will be required for inter subnet routing following are the two extra processing needs to carry out by Nodes.

- Processing at Router
- Processing at Bridge

Each Router needs to check the address serial no and network type if that is not matching to its own address then it needs to tunnel the packet to the Bridge it's connected to.

Each Bridge needs to first unpack the message then it needs to check the destination address , based on that it will decide whether to tunnel the packet to other bridges in the subnet or forward it to the next hop in the path of the destination node.

U = Unpacking Overhead, T = Tunneling overhead

TABLE XIV: PROCESSING OVERHEAD

Total No of Message(M)	Total No of Sub nets (N)	Percentage of inter subnet message(%)	Overhead in normal PAN (M*A*NP)	Overhead in new PAN (A*NP+ N/2*(U+T))	Extra Overhead in new PAN (N/2*(U+T))*(M*P)	Processing over head of Unpack(U)	Processing over head of Tunnling(T)	Normal Processing overhead (NP)	Average path traversed by each message (A)
100	5	5	1000	1075	75	3	3	1	10
100	5	7.5	1000	1112.5	112.5	3	3	1	10
100	5	10	1000	1150	150	3	3	1	10
100	5	12.5	1000	1187.5	187.5	3	3	1	10
100	5	15	1000	1225	225	3	3	1	10
100	5	17.5	1000	1262.5	262.5	3	3	1	10
100	5	20	1000	1300	300	3	3	1	10
100	5	22.5	1000	1337.5	337.5	3	3	1	10

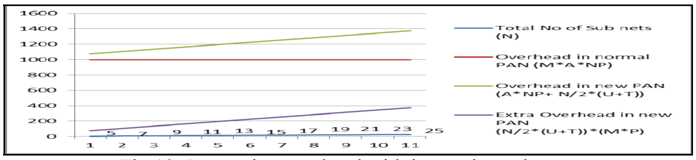

Fig.12. Processing overhead with increasing subnet

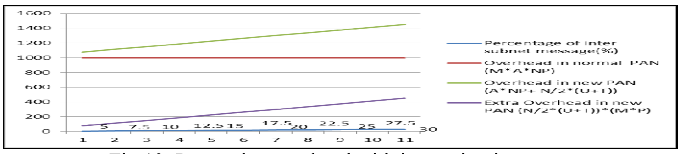

Fig.13. Processing overhead with increasing inter pan

C. Simulation result

Following table gives experimental parameter for NS-3 simulation platform for **figure 14**

TABLE XV: NS PARAMETERS

Sensor node position 3D	Static or random in a defined limit area
Number of sensor nodes	15 to 50
Data packet size	64 Bytes
Data packet period	15s
Experiment duration	300s
Loss model	Friis propagation loss model
Delay model	Constant Speed Propagation Delay Model

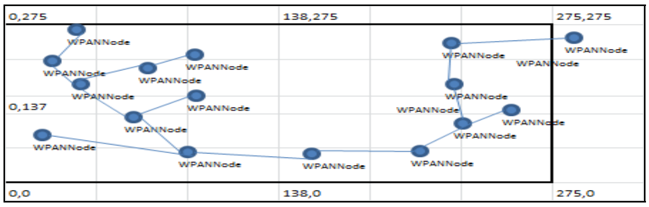

Fig.14. Sample network with WPAN

Delay: Figure 15 depicts a packet delay curve. In this case, when the number of network subtype is increasing, the packet will be relayed by bridges to neighboring subnet.

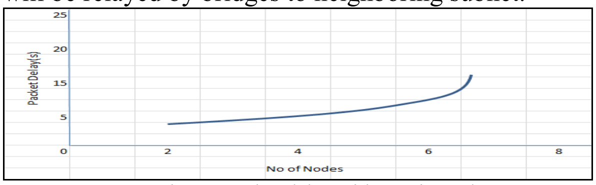

Fig.15. Packet delay with varying sub nets

REFERENCES

[1] Debabrato Giri, Uttam Kumar Roy, "Address Borrowing In Wireless Personal Area Network", Proc.of IEEE International Advanced Computing Conference, (IACC 09, March 6-7), Patiala, India, page no 181-186.

[2] Debabrato Giri, Uttam Kumar Roy, "Multi Channel Personal Area Network(MCPAN) Formation and Routing", International Conference on Industrial Engineering Science and Applications (IESA 2014), April 2-4, 2014, p 73-79.

[3] Debabrato Giri, Uttam Kumar Roy, "Multilevel Address Reorganization Type 2 I N Wireless Personal Area Network", International Journal of Wireless & Mobile Networks (IJWMN) Vol 05, No. 1 February 2013, 01, pages 47 – 64.

[4] Debabrato Giri, Uttam Kumar Roy, "Single Level Address Reorganization In Wireless Personal Area Network", 4th International Conference on Computers & Devices for Communication (CODEC-09), December 14-16, 2009, Calcutta University, India, p 1-4, ISBN-978-1-4244-5073-2.

[5] Debabrato Giri, Uttam Kumar Roy, "WPAN Routing Using Huffman Technique", International Journal of Engineering Sciences, Vol(2), No (2), February, 2013 Pages 49-61.

[6] C. E. Perkins and Elizabeth Royer, "Ad-hoc On-Demand Distance Vector Routing", Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, February 1999.

[7] ZigBee Alliance (ZigBee Document 02130r7) Draft Version 0.90: Network Specification, July 2004.