Multi Channel Personal Area Network(MCPAN) Formation and Routing

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***Abstract*—802.15.4-2003 is the standard for Wireless personal area network(WPAN).The devices forming this networks are Low rate, Low powered, Low memory devices. ZigBee Alliance [18] has provided the specification for Network layer and Physical layer (PHY). Tree and Mesh are the two common topologies for this network. In tree network no routing table is required for routing. After the great success in PAN this technique has also been tried to apply in dynamic Network too. The main problem in applying this tree routing in this dynamic network is all the devices are connected to each other using a single link with parent child relation ship and if the link in broken then that part will be disconnected from the rest of the network and transmission will be disrupted. We have addressed the network depth problem in our paper "Address Borrowing in Wireless Personal Area Network" [8]. Now in some other network configuration the maximum breadth of the network may be attained but the maximum depth of the network may not be attained (because of the asymmetric nature of the physical area) at that part and hence address lies unused. We have addressed this problem in our paper "Address reorganization in wireless personal area network". Here In this paper we have provided a unified Multi channel routing scheme which can be easily applied to tree network so that the network can be used in dynamic application space and overcome the link disruption problem by Multi channeling but without adding any extra overhead of having a routing table.**

Index Terms—PAN; Mesh; Address Reorganizing; Routing; WPAN;Tree;Multi Channel;

I. Introduction

Wireless **P**ersonal **A**rea **N**etworks (WPANs) are used to communicate information over relatively short distances. WPAN require relatively less or no infrastructure compared to wireless local area networks (WLANs). As a result of this feature WPAN allows small, short-range operation, reliable data transfer, and a reasonable battery life, power-efficient, inexpensive solutions to be implemented for a wide range of devices.

Tree and Mesh are the two topologies used in this kind of network. The main advantage of tree address allocation is that it does not require any routing table to forward a message. In that simple mathematical equations are used for address assignment and routing.

II. Overview of Tree Routing

Compared to the other kinds of routing, Distance vector Routing [1, 11, 17], Compact Routing etc. tree routing is simplest as it does not require any Routing table. In tree network topology a central 'root' node (the top level of the hierarchy) is connected to one or more other nodes that are one level lower in the hierarchy (i.e., the second level) with a point-to-point link between each of the second level nodes and the top level central 'root' node, while each of the second level nodes that are connected to the top level central 'root' node will also have one or more other nodes that are one level lower in the hierarchy (i.e., the third level) connected to it, also with a point-to-point link, the top level central 'root' node being the only node that has no other node above it in the hierarchy. The hierarchy of the tree is symmetrical[2], 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.

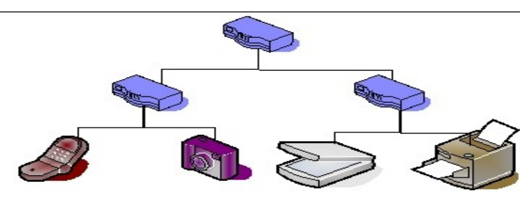


Figure 1: Tree Network

A. Networkdiscovery

When a ZigBee co-coordinator is powered up and set up for forming a network the 1st thing that it used to carry out is check for discovery of any network within its transmission range using 'NLME-NETWORK-DISCOVERY.request' primitive .
NWK layer will attempt to discover networks operating within the device's POS by performing an active scan over the channels

specified in the ScanChannels argument for the period specified in the ScanDuration parameter. The scan is performed by means of the MLMESCAN.request primitive.

NLME-NETWORK-DISCOVERY.request Parameters

Name	Type	Valid range	Description
ScanChannels	Bitmap	32-bit field	The 27 least Significant bits indicate Which channels are to be scanned
ScanDuration	Integer	0x00 - 0x0e	A value used to calculate the length of time to spend scanning each channel:

Table 1 :

The result of the scan is reported by the ‚NLME-NETWORK-DISCOVERY.confirm' primitive. The network descriptor information fields contain the information about all the PAN network operating in the current network space. This information includes the 64 bit PAN Identifiers of the PANs and the logical channels used by them. This information is useful for setting up a new network.

B. Network formation

After completing the Network search the next step is forming the network. Zigbee uses the NLME-NETWORK-FORMATION.request primitive to request that the device start a new ZigBee network with itself as the coordinator and subsequently make changes to its superframe configuration. After getting this request from the next higher layer the ZigBee Network layer If the device is to be initialized as a ZigBee coordinator, the NLME requests that the MAC sub-layer first perform an energy detection scan and then an active scan on the specified set of channels. To do this, the NLME issues the MLMESCAN. request primitive to the MAC sub-layer with the ScanType parameter set to indicate an energy detection scan and then issues the primitive again with the ScanType parameter set to indicate an active scan. After the completion of the active scan, on receipt of the MLME-SCAN.confirm primitive from the MAC sub-layer, the NLME selects a suitable channel. The NWK layer will pick a PAN identifier that does not conflict with that of any network known to be operating on the chosen channel. Once a suitable channel and PAN identifier are found, the NLME will choose 0x0000 as the 16-bit short MAC address and inform the MAC sub-layer. To do this, the NLME issues the MLME-SET.request primitive to the MAC sub-layer to set the MAC PIB attribute macShortAddress. If the NIB attribute nwkExtendedPANId is equal to 0x0000000000000000, this attribute will be initialized with the value of the MAC constant macExtendedAddress. If no suitable channel or PAN identifier can be found, the NLME issues the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to STARTUP_FAILURE.

C. Network Join

Once the network is set up the PAN coordinator opens the network for other device to join by the 'NLME-PERMIT-JOINING.request' primitive. This allows the other node to join the network. Devices that join the network may be of two kind end device or router capable device. End device has no routing capability and can have no child node. The others device are router capable device which can have children either end device or router capable device. Device willing to join the network first checks for existence of any network within its radio range using a energy scan by the primitive 'NLME-ED-SCAN.request'.
Once the suitable network is found the device tries to join that network by using the primitive 'NLME-JOIN.request'. It has the following 5 parameters.

- **ExtendedPANId,**
- RejoinNetwork,
- ScanChannels,
- ScanDuration,
- CapabilityInformation,
- SecurityEnable

The 64 PANID is used for specifying the network to which it wants to join to.

D. Distrubuted 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* (C_m), the maximum depth in the network, *nwkMaxDepth* (L_m), and the maximum number of routers a parent may have as children, *nwkMaxRouters* (R_m), then $C_{skip}(d)$, essentially the size of the address sub-block being distributed *[18]* by each parent at that depth to its router-capable child devices for a given network 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. A parent assigns an address that is 1 greater than its own to its first router-capable hild device. Subsequently assigned addresses to router-capable child devices are separated from each other by Cskip(d). A maximum of Rm of such addresses shall be assigned.

R^{th} Router address at depth D is:

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

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

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

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

E. Network formation

Let Cm=2, Lm=4, Rm=2

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

Table 2

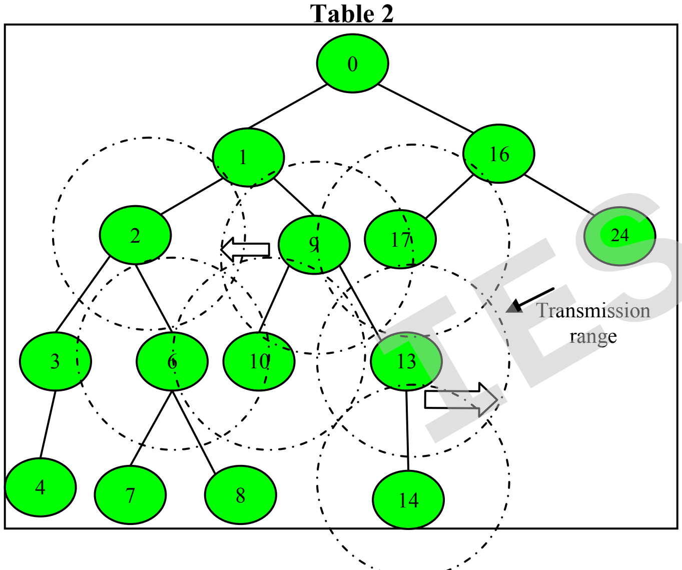


Figure 2: Address Allocation

F. 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. For a ZigBee router with address A at depth d, if the following logical expression is true, then a destination device with address D is a descendant:

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

If it is determined that the destination is a descendant of the receiving device, then it is checked that if the destination is a child end device using the equation

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

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:

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

G. Advantage

Simplicity-It's a very simple network no complex path is formed. A device only communicates with its Parent and Childs.

Scalability – The tree network can grow more than that of mesh networks.

H. Limitations of ZigBee tree routing

Now as we can see although there are 27 channels available (in best case where there is no network in the given transmission range) available for communication only a single channel is chosen and used for forming the Network and subsequent data transfer. Now each device is connected to any other device (its parent or child) with only a single link (Channel).So if we try to use this network in a dynamic network where each devices are movable and still needs to continue data transmission then there will be disruption due to breaking of the link between its parent or child when the device is crossing the transmission range .Also the portion of the network will be unreachable. In **Fig2** node **13** is connected with node 9 and 14 only where node 9 is the parent and 14 is the child. Even though node 17 and node 10 are in the radio transmission range of node 13 they are not connected because of the limitation of Zigbee address distribution and tree routing algorithm. Similarly node 9 is only connected with node 1,10 and 11 only even though node 2,17,6 are in the radio transmission range .Now if node 9 and node 13 started moving in the indicated path then after some time they will not fall outside each others radio transmission range and thus the link between node 9 and node 13 will be broken and thus they transmission halted until node 13 rejoin the network using any other node as parent. In our proposed algorithm we will try to overcome this problem.

III. Proposed Multichannel Routing

In this scheme a node will be allowed to have multiple parents and multiple children so that if the link between a parent to its child get disconnected even then it will be able to stay connected with the network via the other channels. Say for in Fig2 if node9 used to be connected with node2,node12,node 6 and node 13 be connected to node 17 and node 10 as they are also in the radio transmission range then even though the node started in traversing in the indicated path there would have been paths for transferring data within the network. In this multi channel pan we are proposing a scheme which will allow a node to connect with multiple neighbors so that it can stay connected inspite of its mobility. There are 27 channels available for communication but only a single channel is used by a particular PAN. PAN coordinator chooses a 64 bit PAN Identifier by which the underlying network is identified. It also chooses a suitable channel to be used for communication. All the nodes that joins the network uses this channel for sending /receiving message.

As per our proposed scheme a PAN will be identified with combination of two parameters.

- PAN Identifier
- Channel Identifier

So that multiple PAN can have same PAN Identifier but the combination of PAN ID and Channel identifier would be unique.

A. MCPAN Network Formation:

The Network discovery part will remain as it is and there will not be any change to form a network the PAN coordinator will perform the network discovery and then it will go for forming the network.The only change is even if there is a network within its radio range even then it can chose the same PAN Identifier but it must chose a separate channel for communication. That is if as a result of Network discovery a node finds that there is a network with PAN ID ABC11234x and its operation on channel 1 and there are no other PAN with this ID. Then it can start another PAN with the same PAN ID but with a different channel say channel 2. Now if a new node is powered and it also wants to start a new network with the same PAN ID then it have to chose a separate channel for transmission. This helps us in setting up multiple PAN existing within same network area.

B. MCPAN Network Join

Once the network is set up the PAN coordinator opens the network for other device to join by the 'NLME-PERMIT-JOINING.request' primitive. This allows the other node to join the network. Device willing to join the network for the 1st time first checks for existence of any network within its radio range using a energy scan by the primitive 'NLME-ED-SCAN.request'.
Once the suitable network is found the device tries to join that network by using the primitive 'NLME-JOIN.request'. This primitive needs to be modified to add one extra parameter to specify the channel along with the PAN ID.

- **ExtendedPANId,**
- **Channel ID**
- RejoinNetwork,
- ScanChannels,
- ScanDuration,
- CapabilityInformation,
- SecurityEnable

In this paper we have explained the proposed algorithm with 3 concurrent PAN. In our given operating space say there are 3 devices which are capable of setting up a network of its own marked in rose color (0,2,9). Now say node 0 first powered up and finds no network is present it does an energy scan and finds that all the channels are free. The next step it will do is choose a particular channel (1)and PAN ID (ABC11234x) to setup its own network .The final network with its address distribution is depicted in Figure 3.

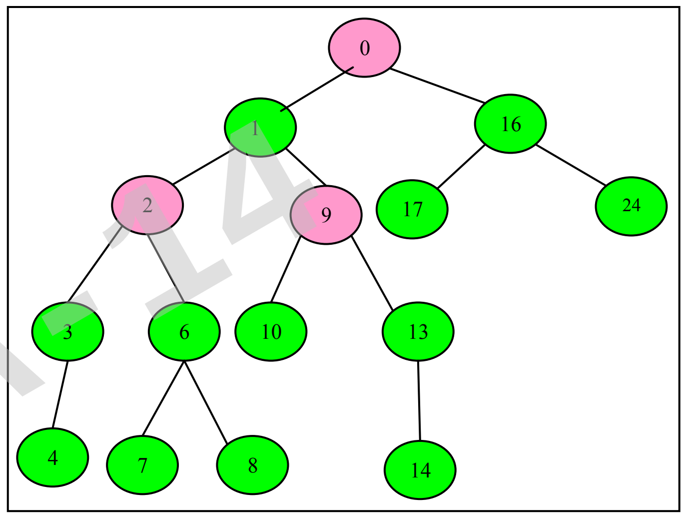


Figure 3: PAN 1

Now say node 2 of figure 3 wants to start the network with the same set of nodes It will scan the underlying channels and select a separate channel(2) and use the same PAN ID (ABC11234x). After that it will start accepting the node joining the network using the primitive 'NLME-PERMIT-JOINING.request'.

On receiving a network join request it will first check if the PAN ID and channel ID is matching with its PAN ID and selected channel. Then only it accepts the request. The final network along with its address distribution is depicted in Figure 4.

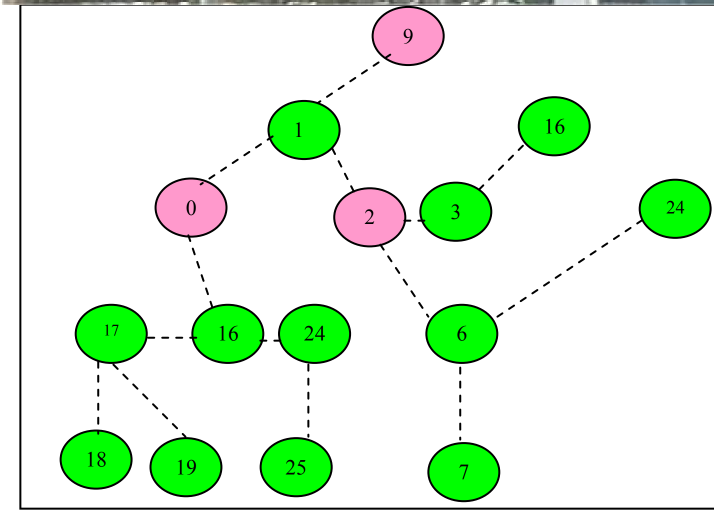


Figure 4 : PAN 2

Now say node 9 of **figure 3** wants to start the network with the same set of nodes It will scan the underlying channels and select a separate channel(3) and use the same PAN ID (ABC11234x). After that it will start accepting the node joining the network using the primitive 'NLME-PERMIT-JOINING.request'.

After the completion of network formation it may form a network depicted in Figure 5.

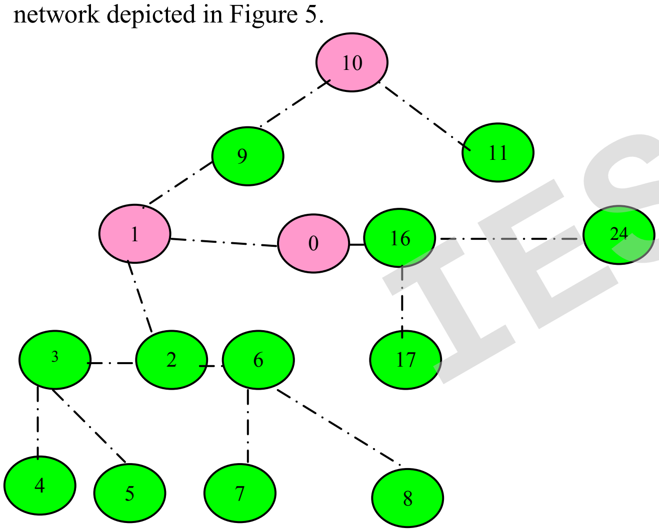


Figure 5 : PAN 3

Please note that in this scheme a node is having multiple network address. Each address is associated with a particular channel. To support this each router capable node needs to maintain a special table called Multichannel Map. It will have the following 3 fields.

- **PAN ID**
- **Channel ID**
- **Network Address**
- **Primary Network**

The table maintained at node 0 of Figure 3 will look like the following .At max this table can have 27 entry 1 for each channel

PAN ID	**Channel ID**	**Primary Network**	**Network address**
ABC11234x	1	Y	0
ABC11234x	2	N	9
ABC11234x	3	N	10

Table 3 : Multichannel Map

Now if we see the whole set of connectivity we can find that the no neighbor a node can have has been increased considerably to show that we can merge the 3 PAN . The resulted network is shown in Figure 6

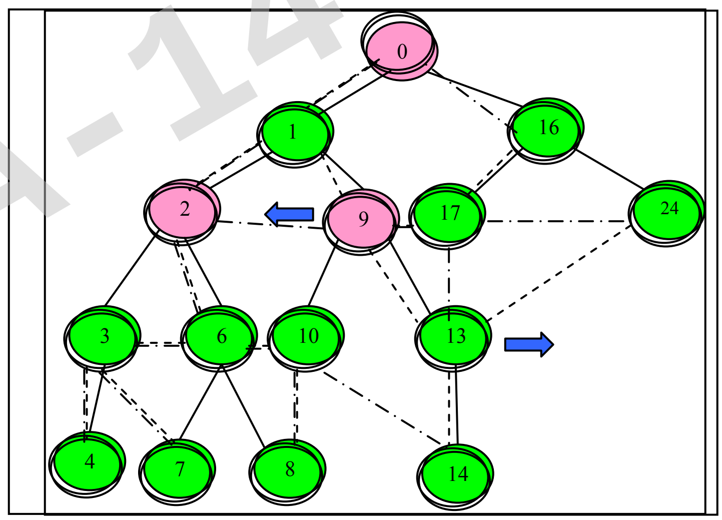


Figure 6: Multichannel network with all the connectivity

If we look at Figure 2 which shows a normal PAN we can find that node 9 is connected with only 3 node 1,10,and 13 but with our proposed modification in Multichannel PAN node 9 now is connected with 5 node(1,2,10,13,17). Similarly Node 13 was connected with 2 node(9,14) in normal PAN but in Multichannel PAN node 13 is now connected with 4 node(9,17,24,14).

Now because of this additional neighbor even if node 9 and 13 started moving in the indicated path marked in blue and come out of each other transmission range even then the will stay connected via other node 24,16,1,2,10 in this case. In this example I have used only 3 channels if we increase the no of channel then it will have more neighbor and hence better connectivity and mobility.

C. Routing overview in MCPAN:

There are two ways with which the routing could be done one is reactive mode and the other is proactive mode. The reactive mode again is divided into two sub categories source scheduled and Failure point scheduled.

1. Reactive Routing
    a. Source scheduled
    b. Failure point scheduled
2. Proactive Routing

Reactive Routing overview: In this mode a node will use its primary network first to send its message if it finds that the message is not delivered then it tries to send the massage using the 2nd Network and if that is also failed then it tries with the other network and so on until all the network is exhausted or the message has been delivered.

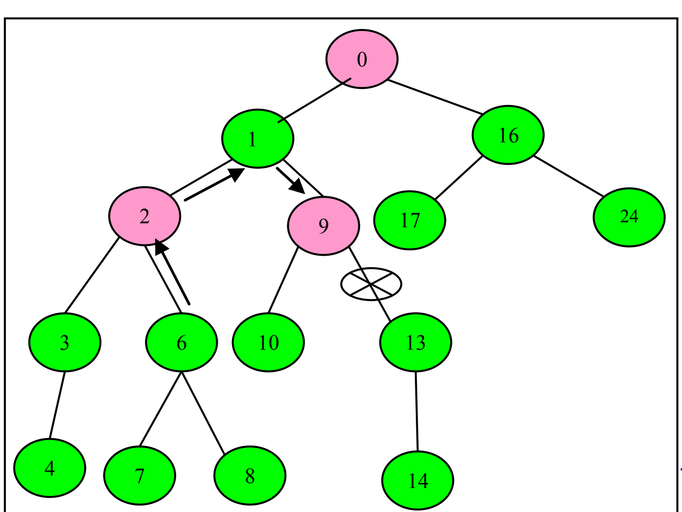
There are two version of this routing. In this paper we will only discuss about the source scheduled routing only.

1. a. Source scheduled: - In this the source node takes the responsibility of the fail transmission and tries to send the message a separate channel.

Lets discuss the algorithm using an example. Suppose **Node 6** of Figure 6 wants to send a message to node **Node 13**. and its Multichannel Map is as follows.

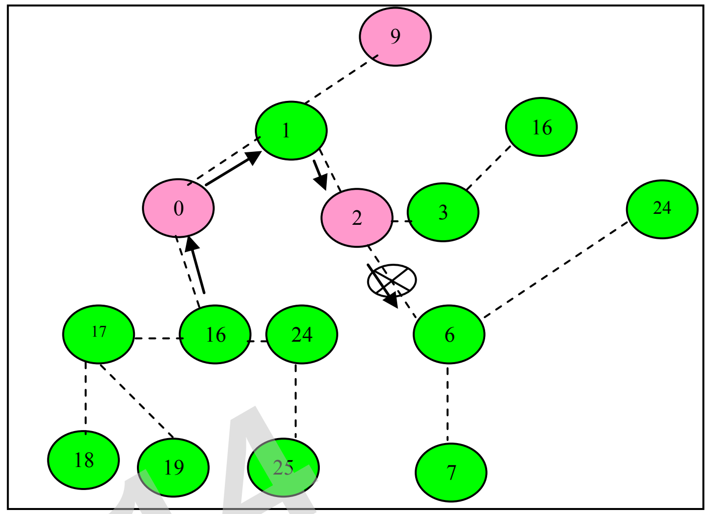
PAN ID	Channel ID	Primary Network	Network address
ABC11234x	1	Y	6
ABC11234x	2	N	16
ABC11234x	3	N	2

It Will 1st try to send the message using the its Primary network that is PAN 1 (Channel 1). And it will follow the following route. 6=> 2 =>1 => 9 =>13.

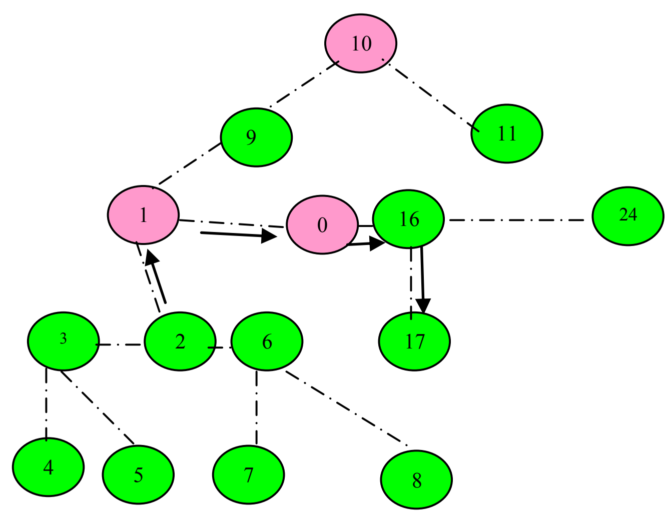


Now if the link between node 9 and 13 is broken because of the movement or any other reason then Node 6 will eventually receive a failure send message.

On receiving this it will send the message using Pan 2(Channel 2, Figure 3) in this Node 6's address is 16 and Node 13's address is 6.It will try to send the message using the path 16 => 0=> 1=>2 =>6.But as the link between node 2 and 6 is broken then this message transfer will also fail.



After receiving the failure notification it will send the message using PAN 3 **Figure 5.** In this case node 6's address is 2 and Node 13's address is 17. It will use the following path to send the message.
2=>1 =>0 =>16 =>17



The advantage of this mode is that it doesn't put any extra load on the network and sends a 2nd message using separate networks only in the case of failure.

But the main disadvantage is every time a resend is done the delay is increased as well. For example if for normal transmission it takes X amount of time then for each retransmission will increase the time by X amount at an average. So if the node is part of 27 channel network then the delay can be increased up to 27X. If the networks demand a continuous data transfer with short delay in those scenario it will not be suitable. For example a chatting application might not meet the user experience if the delay is prolonged.

IV. Related work

Wireless networks have rapidly gained popularity since their introduction in 1970s. However, an investigation into low-cost, low-rate, low-power PAN is relatively new. In [7] authors explored the complex behavior of a large number of small low-power sensor nodes. Energy aware operation of wireless devices is the dominant theme in [14], [16].

Routing in wireless networks has been a fascinating topic of research for long. These routing protocols have to deal with the challenges of wireless networks, namely low-bandwidth, high error-rates and often energy and memory constraints. These algorithms are either table-driven (e.g. DSDV [5], WRP [Shree_Murthy]) or source-initiated, that is demand-driven (e.g. DSR, AODV [4, 6, 3]).A comprehensive survey of these protocols has been done in [9].Address Borrowing has been discussed in [8].There is relatively scant literature on 802.15.4/ZigBee although its applications have been discussed in [14], [9]. Authors provide one of the first studies of the MAC sub layer while the recent paper [15] is a comprehensive performance evaluation of 802.15.4.

V. Conclusion

In this paper we have provided a unified Multichannel network formation and routing scheme which can be used to use WPAN in Business networks where mobility is involved such as wireless sensor network in Mine by allowing the network to be created using multiple channel with marginal overhead in .

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