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CHANNEL ALLOCATION AND BRAIDED DISJOINT MULTIPATH ROUTING IN WIRELESS SENSOR NETWORK

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ABSTRACT

In wireless sensor networks, concurrent transmission causes performance degradation. In this paper, channel allocation based on a new combinatorial technique of Latin square generation and Braided Disjoint Multipath Routing Algorithm (BDMRA) is proposed. The number of nodes in the network is set as the order of the Latin square. The row and column of Latin square is indexed with numbers are used for Channel Allocation. BDMRA algorithm reduces the network redundancy. The established braided paths are disjoint and maintained between the source and destination as an end-to-end transmission path. Path establishment time is reduced since the path connecting the source and destination node requires only the connectivity between the source and destination clusters.

Keywords: channel allocation, braided disjoint multipath, mutually orthogonal latin squares, routing.

INTRODUCTION

Channel as a scarce resource in a WSN greatly influences the performance of a multi-channel WSNs. A channel allocation strategy called MinMax proposes a distributed link-based MinMax channel allocation protocol creating a conflict free schedule transmissions resulting in minimizing the maximum interference (AbusayeedSaifullah*et al.*, 2014).

A Distributed co-ordination based on Latin square, providing a collision free CSMA based channel access in a large scale wireless networks. Latin square scaling, to expand the size of the Latin square and Latin square interleaving algorithm that shuffles and interleaves the Latin square columns alternating the channel access opportunities between the Base station systems (LichunBao*et al.*, 2011).

An adaptive dynamic channel allocation protocol (ADCA) for optimization of both throughput and delay in the channel allocation is proposed. Each dynamic interface maintains multiple queues in the link layer with one queue for each neighbor. The data to be transmitted to neighbors are buffered in the corresponding queue. The neighbor's priority is evaluated for its queue length and the duration of not serving the queue (Yong Ding *et al.*, 2013). An approach where each node update its choice of channel according to the historical record of channels performance to reduce the interference is proposed (Jiming Chen *et al.*,2014). Regret matching based algorithm which can adapt to time-variant flow in channel allocation and network topology is proposed (Lin Gao*et al.*, 2009). Channel allocation problem is modeled as a hybrid game involving Co-operative and Non-Cooperative game. Former is within a communicative session and later is among sessions. Min-Max Coalition Proof-Nash Equilibrium (MMCPNE) channel allocation scheme which maximizes the successful communication sessions (Jun Sun et al.,2006). It provides a specific channel allocation strategy of state distribution over [0,1] which utilizes a Pareto Optimal Strategy (POS).

Braided routing resolves the problem of disjoint paths and maintains the redundancy of the network. Most of the nodes in the network are involved in the primary path and energy efficiency is guaranteed by keeping the braided paths as close as possible to the primary path (Manal Abdullah *et al.,* 2014).

A Network Coding based Co-operative Communication scheme (NCCC) is addressed. It improves the packet loss-resistant capability through network coding and communication fail-resistant capability through co-operative communications (Xingcheng Liu *et al*., 2014). A heuristic Load Distribution algorithm [HeLD] based on a Braided Multipath trying to achieve a well balanced traffic load and maximization of throughput is discussed (MeisamNesaryMoghadam*et al.*, 2014).

LATIN SQUARES AND BRAIDS

Definition

A Latin square of order 'n' is an nxn matrix containing 'n' disjoint symbols such that each symbol appears exactly once in each row and column. Example of Latin square of order 4.

$$A = \begin{pmatrix} 0 & 1 & 2 & 3 \\ 1 & 2 & 3 & 0 \\ 2 & 3 & 0 & 1 \\ 3 & 0 & 1 & 2 \end{pmatrix}$$

Orthogonality

When superimposing two Latin squares of order 'n' say L_1 and L_2, an array of size nxn is obtained $S(L_1,L_2)$ of ordered pairs, where (i,j)th entry is defined by $S(L_1,L_2)(i,j) = l_1(i,j),l_2(i,j)$ for $0 \leq i < n$, then the Latin squares L_1 and L_2 are said to be mutually orthogonal if 'r' distinct ordered pairs are obtained on superimposing. Let the order of Latin Squares be n=4 and $S(L_1,L_2)$ is superposition of L_1 and L_2.

$$L_1 = \begin{pmatrix} 0 & 1 & 2 & 3 \\ 1 & 2 & 3 & 0 \\ 2 & 3 & 0 & 1 \\ 3 & 0 & 1 & 2 \end{pmatrix} L_2 = \begin{pmatrix} 0 & 1 & 2 & 3 \\ 2 & 3 & 0 & 1 \\ 3 & 0 & 1 & 2 \\ 1 & 2 & 3 & 0 \end{pmatrix}$$

$$S(L_1,L_2) = \begin{pmatrix} (0,0)(1,2)(2,2)(3,3) \\ (1,1)(2,3)(3,0)(0,1) \\ (2,3)(3,0)(0,1)(1,2) \\ (3,1)(0,2)(1,3)(2,0) \end{pmatrix}$$

Since there are 12 distinct ordered pairs in $S(L_1,L_2)$, L_1 and L_2 are known as 12-Orthogonal.

Theorem

Two Latin Squares of order 'n' are orthogonal if when the squares are superimposed, each of the n^2 ordered pairs appear exactly once that is if they are n^2 – Orthogonal.

Mutually Orthogonal Latin Squares (MOLS)

A set of Mutually Orthogonal Latin Squares is two or more Latin Squares of the same order, all are orthogonal to one another. MOLS generating matrix can be given as follows,

Let 'L' be a Latin square of order 'n' and let 'G' be an nxn permutation matrix, then 'G' is a MOLS generating matrix if $\{GxL, G^2xL, \ldots, G^{n-1}xL\}$ is a complete set of MOLS. MOLS of order 4 is given below.

Aα1	Bβ2	Cγ3	Dδ4
Bγ4	Aδ3	Dα2	Cβ1
Cδ2	Dγ1	Aβ4	Bα3
Dβ3	Cα4	Bδ1	Aγ2

Figure-1. Example of mutually orthogonal Latin squares.

Braids

Definition: Let 'D' be the unit cube in the positive octant of Euclidian 3D-space, with one vertex of the origin. Hence $D = \{x,y,z \in R : 0 \le x, y,z \le 1\}$ and 'n' can be defined as points $A_1, A_2, \ldots, A_n$ on the top face of D by

$$A_i = \left(\frac{1}{2}, \frac{i}{n+1}, 1\right), 1 \le i \le n \quad (1)$$

Similarly, 'n' points can be defined as $B_1, B_2, \ldots, B_n$ on the bottom face of D by

$$B_i = \left(\frac{1}{2}, \frac{i}{n+1}, 0\right), 1 \le i \le n \quad (2)$$

By adding 'n' polygonal arcs $d_1, d_2, \ldots, d_n$ to D such that,

(i) $d_1, d_2, \ldots, d_n$ are mutually orthogonal.

(ii) for any $0 \le S \le 1$ and $1 \le i \le n$, $E_s \cap d_i$ is exactly one point.

(iii) each d_i begin at same A_j and ends at same B_k.

The resulting collection of 'n' arcs $d_1, d_2, \ldots, d_n$ is called n-braid.

The first relation (ac=ca) is valid for any two letters distant of atleast 2 in the alphabet. The relation (aba = bab) is valid for two consecutive letters in the alphabet. The inverse property is considered while construction. The identity braids with 'n' strings corresponds to 'n' descending strings that doesn't cross.

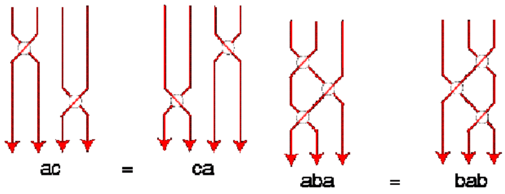

Figure-2. Braided relation.

Braid group

Braided paths constructed within each cluster can be grouped as *Artin's n-braid group*. When the clusters communicate, a new path is established between the braided paths of the clusters and it is said to be the braid product of paths β1 and β2.

Definition

Let β1, β2 ∈*B*n. We shall define a new braid from β1, β2, called the braid product of β1 with β2 and denoted β1β2, as follows: Let β1, β2 lie in unit cubes D1, D2 respectively. Identify (glue) the base (z = 0) of D1 to the top (z = 1) of D2. Then scale the union D1 ∪D2 by a factor of 1/2 and call this D. Clearly the end points of arcs in β1 and β2 are matched up in this identification. The resulting collection of n arcs in D is denoted β1β2, the braid product of β1 with β2.

Theorem

Let β1,β2 ∈*B*n. Then β1β2 ∈*B*n.

Proof: Let β1 lie in D_1, with braid strings $\{d_1^1, \ldots d_n^1\}$, where each d_i^1 begins at A_i^1 and ends at $B_{j1(i)}^1$. Let β2 lie in D_2, with braid strings $\{d_1^2, \ldots d_n^2\}$ }, where each d_i^2 begins at A_i^2 and ends at $B_{j2(i)}^2$. Then, after we identify the bottom of D_1 with the top of D_2, each B_i^1 is identified with A_i^2.

Thus, for each $1 \le i \le n$, the end of d_i^1 (i.e., $B_{j1(i)}^2$ connects to the start of $d_{j1(i)}^2$). So $\{d_i^1 \cup d_{j1(i)}^2 | 1 \le i \le n\}$ is a set of n polygonal arcs in D, and we denote each $d_i^1 \cup d_{j1(i)}^1$ by d_i. Now d_i forms the braid strings of an n-braid, by direct verification of the definition of an n-braid. Since β1 (respectively β2) is a braid, then all the d_i^1 (respectively d_i^2) are disjoint. Thus, d_i must be disjoint, each being the union of d_i^1 and $d_{j1(i)}^2$.

Network model building

A WSN consist of a set of nodes. The Base station acts as the SINK of the network. A communication link 'L' = (p,q) indicates the packet transmission by node p to node q. Any two concurrent transmissions on the same channel are conflicting if there is an interference link from one sender node to the receiver node. In a wireless

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sensor network, topology is considered as an undirected graph G = (S,I) where 'S' denotes the set of nodes in the network and 'I' represent the set of interference links between the nodes.

A subset of the communication link forms the routing tree which is used for data collection at the sink. A node cannot send and receive data at the same time, nor it can receive data from more than one sender at the same time. Hence, every sender is assigned a unique channel.

Generation of Latin squares

Consider a square grid of size 4x4 and the grid cells are assigned values from 1 to 4 randomly such that every number appears exactly once in each row and column. For example, consider the cell occupancy position of '3' as shown in the figure. The row and column of the grids are indexed from 1 to 8.

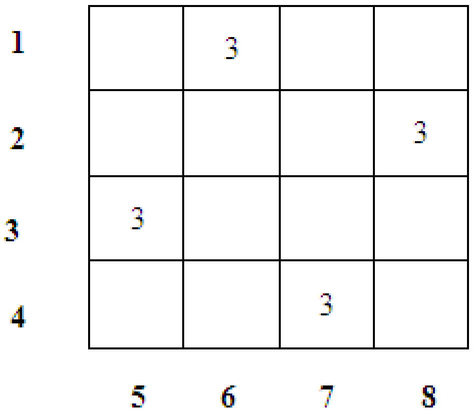
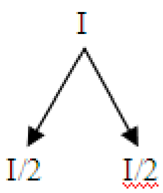


Figure-3. Cell occupancy of number 3.

Cell location set of number '3' is (1,6), (2,8), (3,5), (4,7) with respect to indexing. The sum and the difference between the numbers in all index set is obtained as shown in table.

Elements of index set 'I' = {1,2,3,4,5,6,7,8}

Index set is partitioned into two sets as follows:



I/2 is a subset of the index set 'I' and it can be divided into any number of subsets.

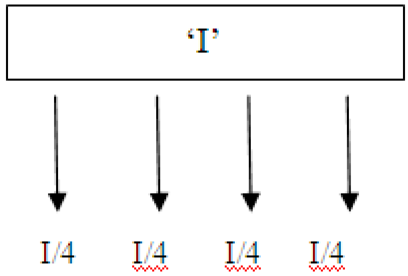


Table-1. Example index set.

Index set 'I' of the number '3'	Sum	Difference
(1,6)	7	5
(2,8)	10	6
(3,5)	8	2
(4,7)	11	3

Elements of 'sum' = {7,10,8,11}
Elements of 'difference' = {5,6,2,3}

The resultant set elements are unique and disjoint. Intersection between the sets constitutes a null set. On satisfying the condition, a unique Latin square can be generated. As the order of the grid size increases, the condition check for null set is not satisfied. In such cases, Latin square is generated by considering the minimum number of repetitive elements.

$$I/2\ (difference) \cap I/2\ (sum) = \{\ \}\ \text{or} \quad (3)$$

LS generation condition (GC)

$$GC = \text{minimum}\left\{\frac{I}{2}(difference) \cap \frac{I}{2}\ (sum)\right\} \quad (4)$$

For a grid size of 8 x 8, the minimum number of repetition is found to be '1'.

CHANNEL ALLOCATION BASED ON LATIN SQUARE

In a wireless network, every node is assigned a symbol from a Latin square. When two nodes are assigned two different symbols, it is said to be conflict free and conversely two nodes are said to be conflicted when the same symbol is assigned to them. In Latin square, the channel number is assigned as the row index and the order of occupancy is assigned as the column index. Numbers in the grid represent the nodes in the network. Consider the index set (1,6), 1 -indicates the channel number and 6 – indicates the order of occupancy.

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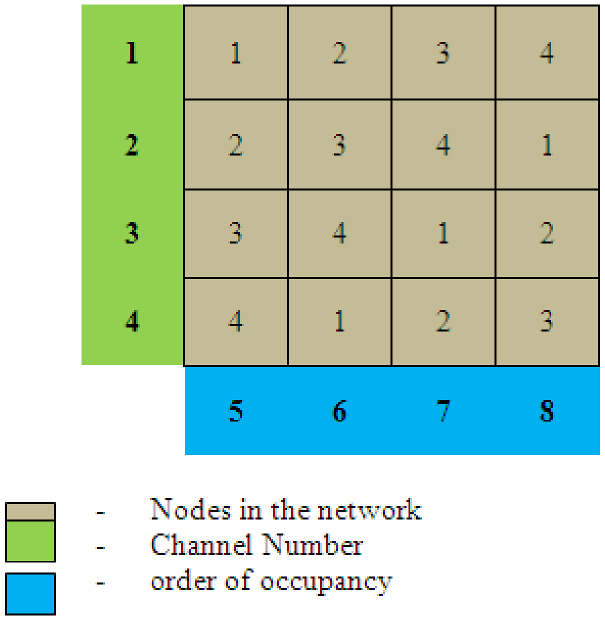

Figure-4. Channel allocation

Algorithm

Step 1: Number of nodes in the network is set as order of the grid size.
Step 2: Numbers are randomly deployed in the grid cells.
Step 3: Grid rows and columns are indexed with the channel number and the order of occupancy.
Step 4: Select a number from the cells.
Step 5: Identify the index sets of the selected number.
Step 6: Obtain the difference and the sum between the two numbers of all index sets.
Step 7: Intersection between resultant sets of sum and difference is obtained.
Step 8: If the resultant set is a null set, the grid cells form a unique Latin square
Step 9: If the nullity condition is not satisfied, the set with the minimum number of elements of intersection is considered for Latin squaregeneration.

BRAIDED MULTIPATH ROUTING

Objective of an alternate path routing in a WSN is to reduce the frequency of route rediscovery providing a high path resilience against route failures. Routing includes both proactive and reactive concepts. Proactive routing computes routing table before the need while in reactive, nodes do not maintain any global information. Multipath is dynamically searched on demand.

The nodes are divided into clusters. In this work, the proactive routing is used for communication within a cluster and reactive routing for across the clusters. Each cluster will have a root node and neighbor nodes to the root node constitute the sub-root nodes. Sub-root nodes construct their own sub-branches. Only paths from different sub-branches are accepted thereby increasing the possibility of alternate paths.

Fault Tolerance Rate(FTR) α **No. of Paths constructed between a node and SINK** (5)

Number of Root nodes α Number of Disjoint Braided Paths (6)

Only one hop neighbor with a minimum distance to the Base Station is considered as the root node.

Node's Neighborhood

The NeighborhoodN(v) is the set of nodes that reside within the transmission range of node v, which means the vertices adjacent to. If 'v' is included as the neighborhood is called closed neighborhood of v and it is represented as N[v].

k- Neighborhood

The K-Neighborhood of v, $N_k(v)$ is the set of nodes with distance atmost K from v.

$$N_k(v) = \{u|u\epsilon v \wedge d(u,v) \leq K\} \quad (7)$$

Cluster identification

A cluster is any subset of nodes c − v, yϵv is the cluster head and $G_c = (C,E_c)$is the cluster graph.

$$E_c = \{(u,v)|u,v\epsilon c \wedge (u,v)\epsilon E\} \quad (8)$$

If G_c is connected, then the cluster is connected. $d_c(u,v)$ is the shortest path inside the cluster and the cluster radius is the maximal distance between y and any other node V€C.

$$\text{Max}_{v\epsilon C}\, d_c(y,v) \quad (9)$$

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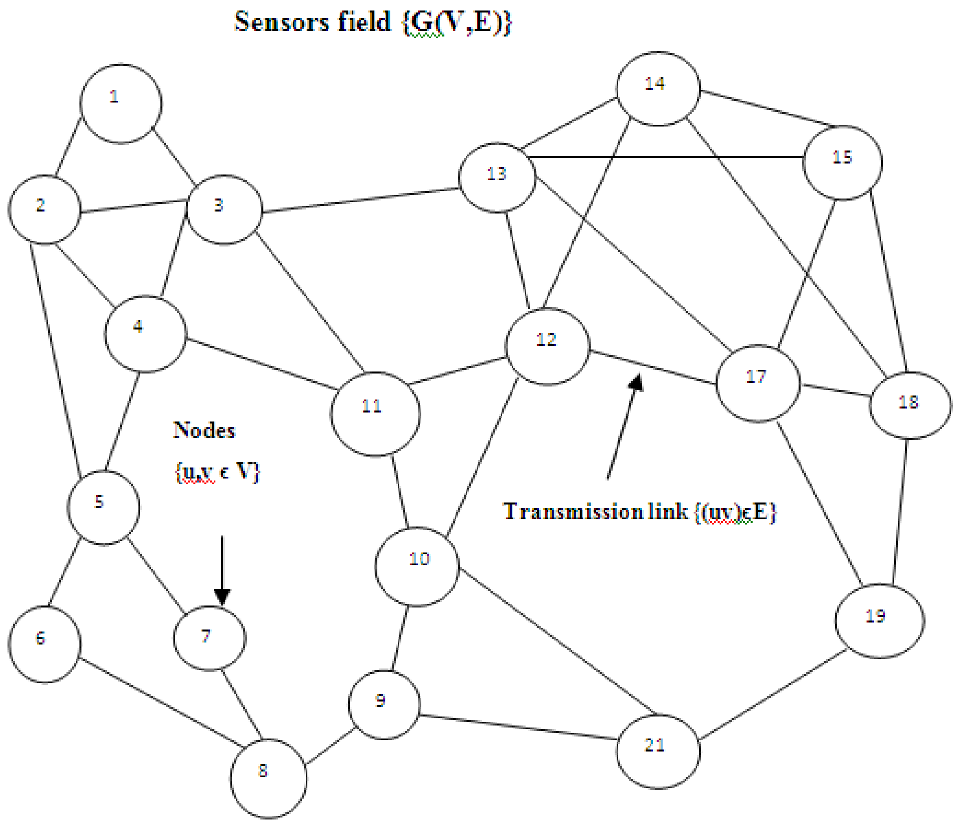

Figure-5. Graphical representation of a WSN.

BRAIDED MULTIPATH ROUTING WITHIN A CLUSTER

Network grid area is partitioned into cages by KenKen approach in which the wireless sensor network area is divided into grid [variable size] which is always a square involving mathematical operation whose solution requires a combination of logic and arithmetic operations. All nodes in the network is assumed to know about the location information of its neighbor nodes since the network considered is a static wireless sensor network.

The Base Station (BS) broadcasts RRM to all nodes of the first cluster with a specific radio range in the following format and every node replies to it.

<Root_ID, HC > (10)

Root_ID ⟶ ID of the sensor node replying to the Route Request Message to the BaseStation.

HC ⟶ Hop count i.e. Number of hops between the replying node and the Base Station.

Node with the single hop count and minimum Line of Sight distance with Base Station is considered as the root node of the cluster.

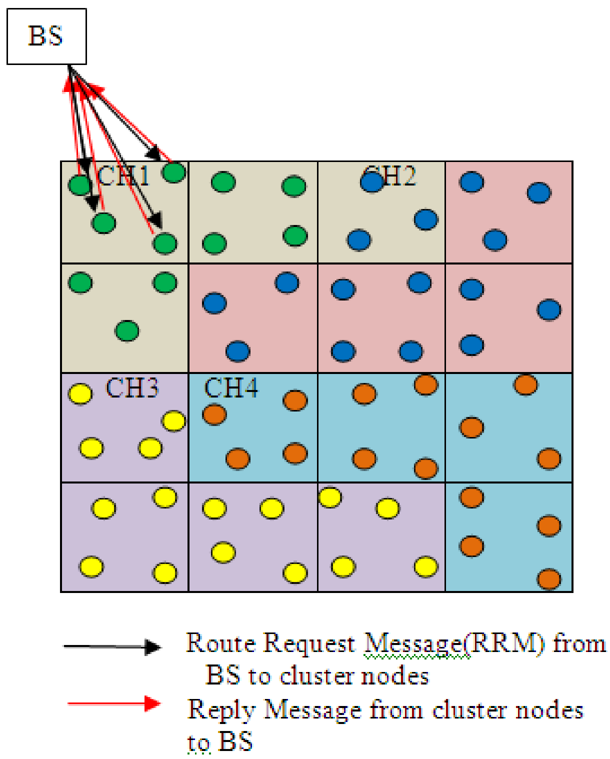

Figure-6. Identification of cluster head.

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CONSTRUCTION OF DISJOINT BRAIDED MULTIPATH

The purpose of braided multipath is to provide an energy efficient recovery from failures of the paths between the SINK and source node. The SINK node sends the alternate path reinforcement message to its next most preferred neighbor node. The path reinforcement message is carried by the rest of the nodes in the network to its neighbors towards the destination node.

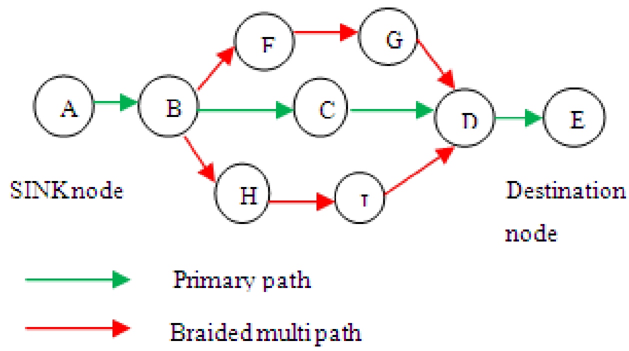

Figure-7. Example braided paths routing between node 'A' and 'J'.

Defining routing table

After root node selection, all nodes define its routing table as follows:

<Parent_ID, Root_ID, N_hops>(11)

Parent_ID → ID of the nodes to RRM (Route Request Message)
Root_ID → ID of the node broadcasting the RR message
N_hops → Number of hops between the parent and the root node.

In Figure-8, two braided paths ABFGDE and ABHIDE are constructed between the SINK and Destination nodes A and E. The routing tables are as follows:

Table-2. Routing table for path ABHIDE.

Parent_ID	Root_ID	N_hops
B	A	1
H	B	1
I	H	1
D	I	1
E	D	1

Table-3. Routing table for path ABCDE.

Parent_ID	Root_ID	N_hops
B	A	1
C	B	1
D	C	1
E	D	1

Table-4. Routing table for alternate braided path ABFGDE.

Parent_ID	Root_ID	N_hops
B	A	1
F	B	1
G	F	1
D	G	1
E	D	1

The nodes within the radio range of the root nodes will reply to the RRM and initializes its routing table by deleting the already existing paths. Only the nodes with minimum number of hop count will be included in the routing table. All established paths are assigned a Path Tag (PT). Concurrent transmission of multiple route request messages leads to the duplicacy of paths. On non-existence of the received PT in the routing table, the node is included as the new parent else excluded. All established paths are assigned an unique ID with the cluster number.

ROUTING ACROSS THE CLUSTERS

All possible braided paths are identified within a cluster and are maintained as a table. When there is a communication between the BS and a node in a cluster 'n', the BS will broadcast a Route Request message containing the destination node ID to its nearer clusters root nodes.

<R_ID, C_ID, DN_ID>(12)

R_ID - ID of the destination cluster's root node
C_ID - ID of the cluster
DN_ID - ID of the destination node

Communication between the root nodes of clusters

The root node of the cluster nearer to the BS will broadcast the Route Request Message to the root nodes of the clusters in the downstream as follows:

<R_ID, Path_ID, LN_ID, C_ID>(13)

R_ID - ID of the root node of the cluster sending RR message
Path_ID - ID of the path in the cluster
LN_ID - ID of the last node in the identified path
C_ID - ID of the cluster sending the RR message

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BRAIDED MULTIPATH ROUTING ALGORITHM

Algorithm (Communication within cluster)

Step 1: Identify the root node of the cluster
Step 2: Define the routing table
Step 3: Construct the paths between the root node and its neighbor nodes
Step 4: Identify all possible paths between the nodes until the last node of the cluster is reached

Algorithm (Braided Path establishment and communication between the clusters)
Step 1: Base Station broadcasts the Route Request Message (RRM) to its neighbor root nodesalong with destination node ID, Cluster IDand Root ID
Step 2: Upon receiving the RRM, the root node nearer to the destination cluster will send thepath establishment request message to the destination node's root node along with itsRoot ID, Path ID, last node ID of the selected path
Step 3: Destination root node selects a path from its routing table containing the destinationnode.
Step 4: Root node replies to the last node in the selected path of the cluster which has sent therequest message by sending its selected path ID containing the destination node.
Step 4: Last node of the path includes the received destination path ID in its table.

Braided Path Routing establishment

The root node will select a path randomly from the cluster. The last node in the selected path will send a Route Establishment Message (REM) to the root node of the destined cluster or to the next level cluster in the downstream. On receiving the REM, the root node will select the path containing the ID of the destination node and establishes a connection between the previous cluster and the current cluster.

The Route establishment process is repeated, until the destined cluster node is reached. The same path is maintained for the reverse communication between the destination node and the SINK. Root node of the destination cluster will reply to the last node of the selected path as follows.

<R_ID, Path_ID, N_ID>(14)

R_ID – ID of the root node
Path_ID – ID of the selected path containing the destination node
N_ID – ID of the destination node

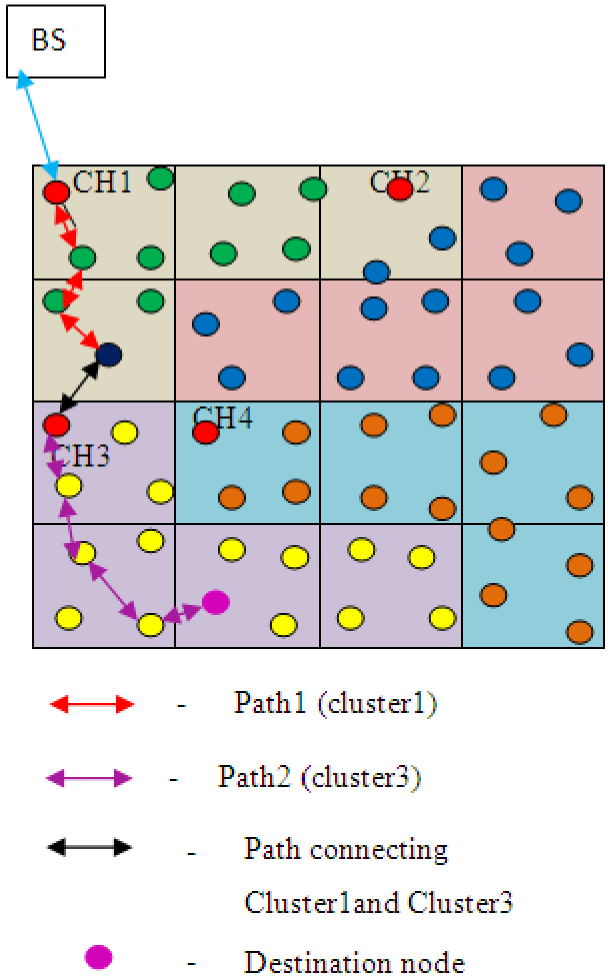

Figure-8. Established braided path between SINK and destination node.

CONCLUSIONS

In this work, we have proposed a novel method of generating Latin Squares for channel allocation in wireless sensor networks. The work discussed provides an efficient way of establishing Braided Disjoint Multipath in a clustered wireless sensor node environment using the Kenken method. This study integrates the existing disjoint path and Braided Multipath in routing which can efficiently reduce the time for establishing the path between the SINK and the destination node. Optimal energy utilization in reactive routing for communication between the clusters in the network through the braided disjoint multipath routing is the key advantage of the proposed approach.

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