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Dynamic channel allocation using Mutually Orthogonal Latin Squares in wireless sensor networks

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Abstract
In wireless sensor networks, efficient channel allocation plays a key role in effective network communication. In this paper, a new combinatorial approach based optimal selection of nodes and CA (Dynamic Channel Allocation) through KenKen approach is proposed. Optimal nodes required for a network topology is calculated and KenKen grid size is set as the cage size for the deployment area. Depending on the cage generation order, channels are allocated. SNR (Signal-to-Noise) ratio optimization and BER (Bit Error Rate) minimization is also studied.

Keywords: Channel Allocation, KenKen, Mutually Orthogonal Latin Squares, Mobile Node Position Location.

1 Introduction / Literature survey

Dynamic Channel Allocation (CA) greatly influences the performance of a multi-channel WSN and ensures reduction of both co-channel interferences and number of concurrent transmissions. In link-based approach, every link(node) between the nodes is assigned a channel and channel allocation is done through Mutually Orthogonal Latin Square(MOLS). In [1], a distributed protocol for link scheduling based on Min-Max channel allocation conflict-free scheduling for packet transmission in the network was proposed. Decentralized protocols for efficient, scalable and adaptive channel allocation and dynamic network were given. Based on the nodes location, the WSN deployment area is divided into grids and LS are applied to the grids and then channels are dynamically scheduled using an algorithm called as Grid based channel allocation and access scheduling algorithm(GAALS) [2].
A receiver based GBCA protocol (using game theory) minimizes the total network interference (link-based). The protocols are implemented in a distributed way and are evaluated with respect to network performance and also compared with a centralized greedy approach [3]. WAVE is practical and simple, network traffic aware distributed joint channel allocation and time slot assignment. Data gathering delays are minimized and data packet transmission is done in a cyclic fashion and is delivered to the sink with negligible packet loss at the physical layer [4]. The desirable features of WSN such as constraint power supply, limited computational complexity and short-range radio communication are key issues while designing a multi-path routing protocol [5].
On demand hybrid multipath routing (OHMR) protocol features two novel characteristics, multi node disjoint and braided routing paths between the source and the destination node. The end-to-end transmission path is maintained for a longer period than multi-path routing schemes. A high success rate of packet delivery ratio is reported [6]. A medium access scheme based on Latin Squares MALS protocol with time-division channel access scheduling and schedules are generated for ad-hoc network nodes. In the Latin Square, the row denotes the node index and the column denotes the time-slotted channels [7].

2 Latin Squares(LS) and KenKen

Definition
A Latin Square of order ‘n’ is an array of n x n cells, where ‘n’ is a positive integer such that each symbol appears exactly once in both row and column. Examples of LS of order 3.

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

2. 1 Orthogonality

When two LS of order ‘n’ are superimposed say L_1 and L_2, and array S (L_1, L_2) (i, j) = {L_1(i, j), L_2(i, j)) for $0 \leq i < n$. then the Latin squares L1 and L_2 are said to be mutually orthogonal if ‘r’ distinct ordered pairs are obtained when we superimpose the two Latin Squares [2].

Theorem 1:
A Latin square has an orthogonal mate iff it contains ‘n’ disjoint transposes[8].

2. 2 Kenken formulation

Kenken can be defined as a grid[variable size] which is always a square whose solution requires a combination of logic and arithmetic operations (figure 1).

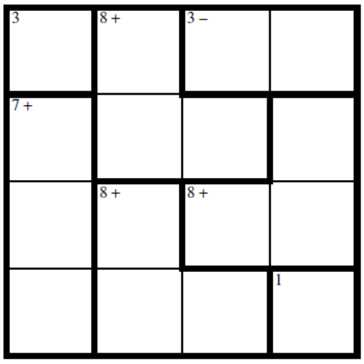

Figure 1: Example kenken Matrix

Latin square principle is implemented to fill the value of grids as the nxn array contains digits from 1 through 'n', where each symbol appears exactly only once in each row and each column in any order. The grid area is divided into cages each with a goal under an operation such as addition, subtraction, multiplication and division.

2. 3 Strategies in kenken

X-wing strategy creates an organized list of elements/numbers and by using the constraints gives an unique solution(Polya). Some of the other strategies are fault line and parity in which the entire matrix grid is cut by the fault line into smaller rectangles and follows the "parity of cages". Stacked strategy deals with the cages which covers the single row or column of the grid. These stacked cages are used to eliminate the possibility sets. Two cages oriented at right angles[tangential] to each other forms orthogonal cages and when they appear parallel lines in the same position forms parallel cages and these cages need to be filled with different numbers. Counting strategy can use simple arithmetic operations.

2. 4 Types of kenken

In abstract kenken, the entries can be numbers, symbols, characters, etc., and the operation can extend beyond binary operations as illustrated in figure 2.

Number of cage squares	Addition	Subtraction	Multiplication	Division	Remarks
2	11+ 10+ 3+	5-	10x 24x 30x	2% 3%	-
3	6+ 7+ 15+ 14+ 10+	NIL	15x	NIL	-
3	4+ 5+	NIL	2x 3x 25x 75x	NIL	Forced constraint (three squares in 'L' shape)

Figure 2: Example Goals

2. 5 Kenken problem generator

A kenken problem of size nxn array,

(i) Starts with an arbitrary solution that satisfies the Latin square condition.

(ii) Then the entries in the rows and the columns are shuffled.

(iii) For the initial kenken grid, a modulo 'n' addition is chosen with all entries being shifted up by 1 using kenken generating formula,

$$\text{Cell } i, j = ((i+j) \bmod n) + 1 \qquad (1)$$

3 Network model building

In WSN each sensor node in the network has the information of itself and its neighborhood nodes. A WSN topology can be represented as an undirected graph G = {S, L} where 'S' is the set of sensors or nodes in the wireless network and 'L' is the set of links between the sensors. The end point in 'L' is called as one-hop neighborhood and the two nodes which don't have any link between them but shares a common one-hop neighborhood node are called as two-hop neighbors. A multihop scenario is given in figure 3. End to end packet transmission delay is reduced in multihop.

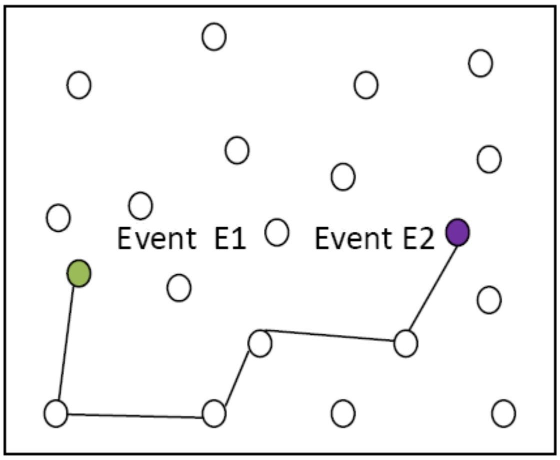

Figure 3: Packet transmission

3. 1 Optimal selection of nodes in network deployment area

Coverage area is less in random deployment of nodes. To overcome this problem a new approach is proposed. The topology is of grid of X x Y. Physical interferences includes urban and indoor structures inside the deployment area. The network area is divided into numerous small regions called as zones say X_0xY_0; X_1xY_1 and in every zone nodes are deployed randomly. For example [X0, Y0] is 10x10 ft, i. e from an x-y coordinates of (1, 1) to x-y coordinates of (1, 10) (y-coordinate represents the diagonal end point of the region).

The node through which the trackers are to be connected and configured is connected to the node/Access Points. Each mobile node is equipped with the android application and connected to server. The RSS from the node which is in the vicinity to send/receive packets with the mobile node is tracked in the laptop and the signal strength (SS) are noted.

The values are tabulated showing the coverage area of the individual node. Mobile node is now configured with the next node in the network and SS (signal strength) of all the nodes are examined at different locations in the network.
The topology of the nodes is changed and at different locations RSS is obtained. Base on the observations the optimal number of nodes required for the network coverage in the deployment area is determined. The connectivity details are tabulated in figure 4.

Study dimension	Zones	Access location	Server
(1, 1, 10, 10)	Zone1	Tracker r1	Connected
(1, 1, 11, 20)	Zone2	Tracker r2	Not connected
(11, 20, 21, 40)	Zone3	Tracker r1	Connected
(21, 40, 41, 80)	Zone4	Tracker r2	Connected
(41, 80, 81, 100)	Zone5	Tracker r1	Not connected

Figure 4: Study of RSS of nodes deployed randomly in the proposed area

The implemented node deployment strategy maximizes the coverage area and also establishes a fully connected network graph.

3. 2 Operational flowchart for optimal selection of source

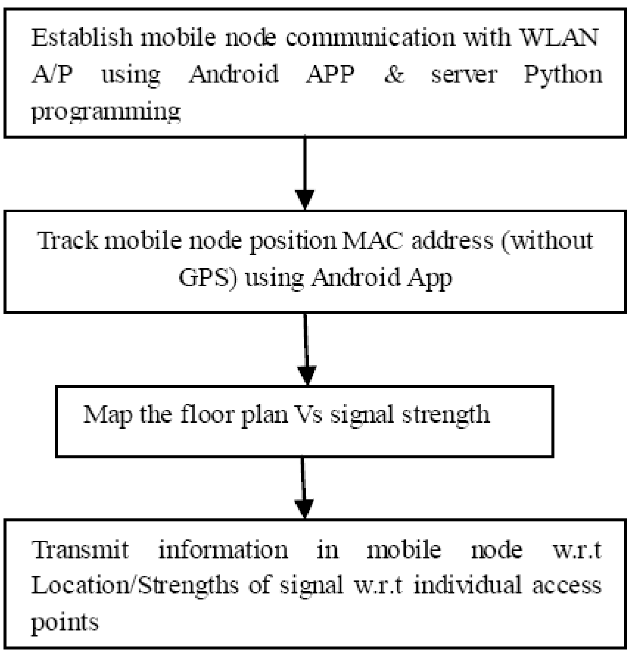

Figure 5: Operational flowchart

3. 3 ALGORITHM SOURCE/SERVER:
Step 1: Listens for incoming packets connections from the client.
Step 2: Set the transmit power for the configured node.

DESTINATION/CLIENT:
Step 1: Connect the server with the access point
Step 2: Configure the mobile node with the access point.
Step 3: Track the RSS (Received Signal Strength) of the mobile phone with respect to the access point.
Step 4: Step 3 is repeated at different mobile node locations in the network area.
Step 5: RSS readings are observed for different locations of access points.

3. 4 Analysis through ken-ken approach
The network deployment area is divided into grids of size nxn. Kenken grid size is set as the size of the network grid. Two nodes are said to be conflict free, if they are in separate cages with different scheduling time and contrary holds true. The grid size of the network area is considered as 4x4.

Algorithm to generate cages for 4x4 grid size
Step 1: Consider a two dimensional array of cell with an “uncaged flag’ value of -1 to all cells in the grid.
Step 2: Cage size is randomly selected limited to (1- n) cells where ‘n’ is the size of the array and the first cell in the grid with uncaged flag is set as the root node.
Step 3: Cages are numbered from 1 as they are generated.
Step 4: Step 2 &Step3 is repeated till all adjacent cells to the root node are added randomly until the pre-determined size of the array or all its adjacent cells has already been caged.

3. 5 KCAS algorithm
KenKen based Channel Allocation and Scheduling algorithm uses the cage property of kenken in channel allocation. The network deployment area is divided into uniform grids of square shape. The cages are generated and are numbered from 1 to N (N-the last cage generated) Kenken grid is mapped with the network area grid as in figure 6. Nodes in cage 1 will be first allocated the channel for communication followed by the other cages with respect to cage number in ascending order. This algorithm guarantees both good communication link quality and low computational complexity.

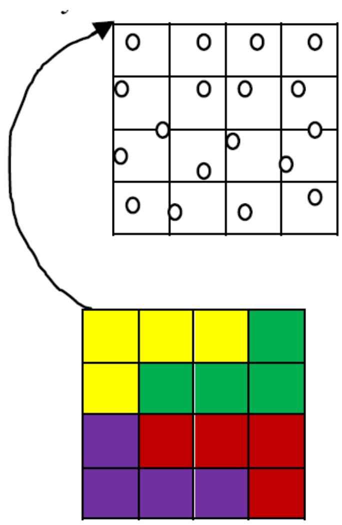

Figure 6: Mapping kenken cages with the physical network deployment grid area

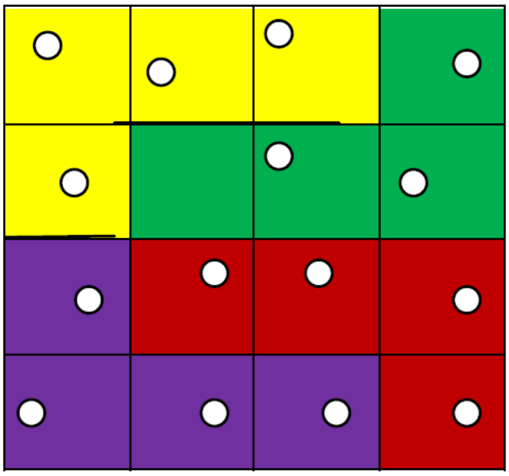

Figure 7: Mapped kenken cages and physical network deployment grid area

3. 6 Flowchart of KCAS algorithm

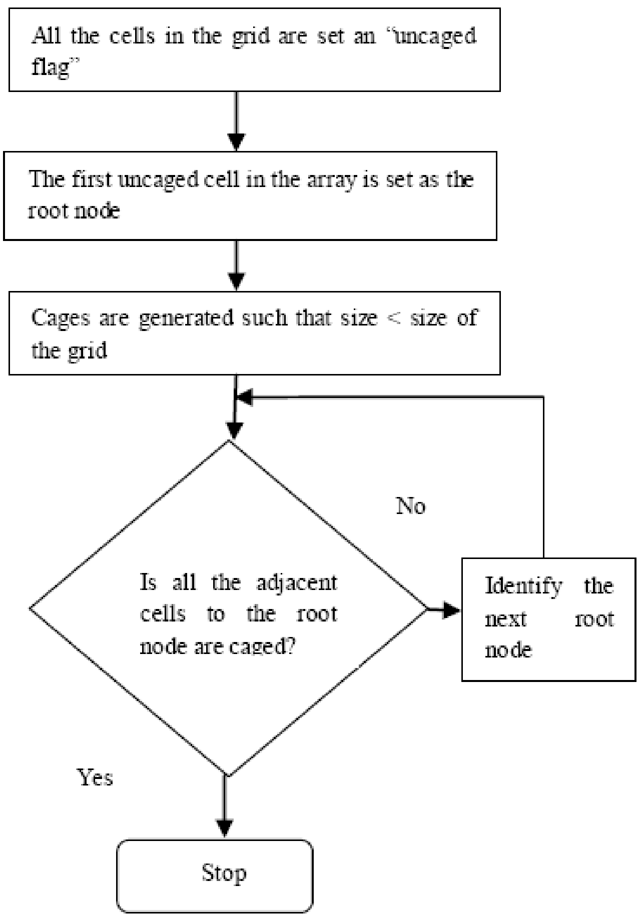

Figure 8: Flowchart of KCAS algorithm

4 Cluster formation and cluster head selection: Nodes in a cage form a cluster. In a cluster, the node with minimal line-of-sight distance with the BS (Base Station) with high success rate of Tx/Rx of packets is considered as the Cluster Head of the cage. Each cluster head is assigned a number as CH1, CH2, …., CHn (figure 9), Where 1, 2, …., n are the cage numbers, n denotes the final cage.

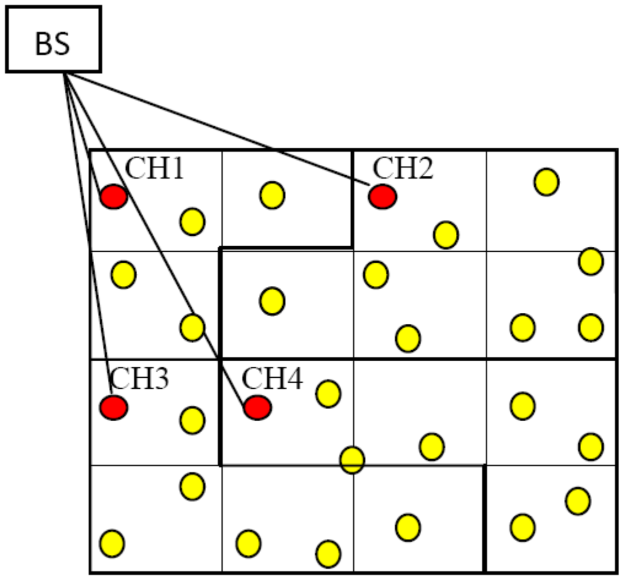

Figure 9: Selection of cluster head

4. 1 Analysis of collisionless model:
KCAS algorithm provides a collisionless transmission resulting in less energy consumption and increased network. The nodes in active mode do not collide with one another but the reverse may occur. Probability of successful packet transmission using Binomial principle is,

$$\mathbf{P} = \binom{n}{k}\, \mathbf{p}^{\mathbf{k}}\, \mathbf{q}^{\mathbf{n-k}} \qquad \mathbf{(2)}$$

Where,
P – Number of 'k' success in 'n' transmissions
n – Number of transmissions
k – Number of successful transmissions
(n-k) – Number of failure transmissions
P – Probability of success
q = 1-p = probability of failures

If a transmission slot has a node which is conflicted still there is a chance of collision free transmission when the rest of the nodes in the transmission slot don't have any conflict.

4. 2 Collision avoidance:
A new method in reducing collision is provided. As the cluster head of the first cage will be broadcasting a transmission time(T_t) message to all other cluster heads in the network before it starts transmitting(figure 10). On receiving the $T_{t,}$ cluster heads will broadcast it to all sensors in its cluster(figure 11). Sensors will calculate its sleep time (ST) and go to the sleep mode once the timer is set.

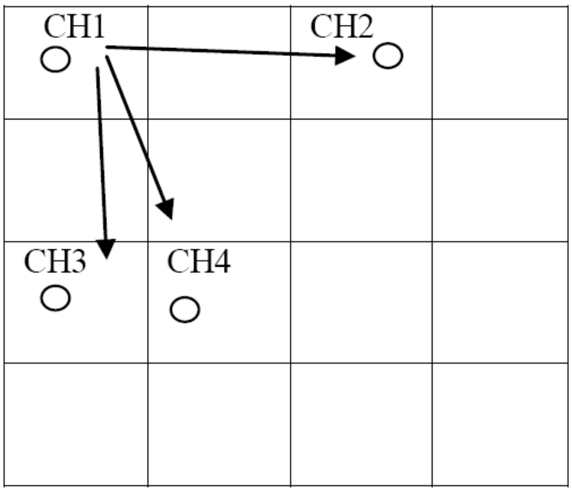

Figure 10: CH1 transmits its Transmission time to all other CHs in the network

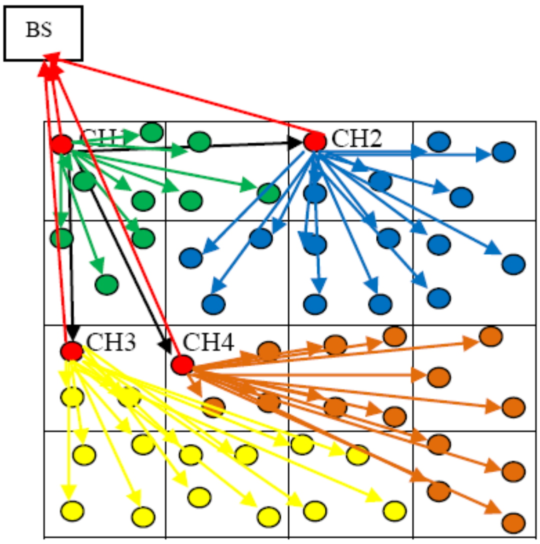

Figure 11: Transmission time message broadcast between the cluster head and the sensors

The sleep time is set as the timer period and once the timer reaches zero, all nodes will move to the listening mode(LT). When cage1 is in active mode, sleep time is applicable only from cage 2. The varying sleep time (ST) for cages is calculated as,

When CN = 2

$$\textbf{ST(CN2)} = \frac{Tt(CN1)}{2} \quad (3)$$

When CN = 3

$$\textbf{ST(CN3)} = \frac{Tt(CN1)*3}{2} \quad (4)$$

When CN = n
Where 'n' is the last cage in the grid,

$$\textbf{ST(CNn)} = \frac{Tt((CN1)*CNn)}{2} \quad (5)$$

Tt - transmission time of cage1 (in seconds)
CN - cage number
LP - Listening Period

Timer period (TP) = ST of the cage **(6)**

LP = (ST+1) to Tt(CN1+CN2+.......... +CNn-1) **(7)**

Nodes in the sleep mode save more than half of the wasted energy. An improved collisionless transmission environment is achieved with this method.

5 Analysis of BER minimization and SNR optimization:

Assuming that a bit with error is transmitted upto the last node in the communication, then Bit-Error-Rate of the transmission with 'n' number of hop links is denoted as BER_{route} [13] and calculated as,

$$\textbf{BER}_{\textbf{route}} = \textbf{1- (1 – BER link) n hop} \quad (8)$$

SNR optimization:
The SNR is calculated as in [12]

$$\textbf{SNR} = \textbf{P}_{\textbf{rss}} \textbf{ – Ni – Ne} \quad (9)$$

P_{rss} – received signal strength
Ni – Internal noise
Ne – environment noise

Conclusion

The work discussed determines the position of a mobile device (or) node in a topology independent of GPS. The mobile node is in communication with WLAN access point(s) and provides the signal strength of the access points, the address and subsequently the variations in signal strength. This facilitates a one to one Correspondence between the position of the access point & the position of the mobile node. This work integrates the existing industrial technologies that can utilize the positional information of a mobile node. This study has proposed a KenKen based dynamic channel allocation and scheduling algorithm in Wireless Sensor Networks. The key advantage of the proposed approach is optimal energy utilization by assigning variable sleep time to nodes in network which increase the lifetime of the network.

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