Space Division Multiple Access Scheme Based on Uniform Latin Squares for Wireless Sensor Networks

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Summary
A Uniform Latin square of order $k = m^2$ is an k x k square matrix that consists of k symbols from 0 to k-1 such that no symbol appears more than once in any row or in any column. This property is also maintained in any m x m area of main subsquares in a k x k Latin square. The uniqueness of each symbol in the main subsquares presents very attractive characteristic in applying Uniform Latin squares to time slot allocation problem in sensor networks. In this paper, we propose a space division multiple access (SDMA) scheme for wireless sensor networks based on Uniform Latin squares. The SDMA divides the geographical area into space divisions, where there is one-to-one map between space divisions and time slots. Because of the uniqueness of the symbol value in any main subsquares, the mapping of time slots into space divisions guaranties a collision-free medium access to sensor nodes. We also study the effect of the use of multiple transmission power levels and corresponding packet lengths on the system throughput. To do so, a self-controlled multiple power level algorithm has been proposed to improve the throughput of a multiple power level system.

Key words:
Wireless sensor networks, Medium access control protocol, Space division multiple access, Multiple power level system, and Latin squares.

1. Introduction

A wireless sensor network is a special network with large numbers of nodes equipped with embedded processors, sensors and radios. These nodes collaborate to accomplish a common task such as environment monitoring or asset tracking. In many applications, sensor nodes will be deployed in an ad hoc fashion without careful planning. They must organize themselves to form a multi-hop, wireless communication network.
A common challenge in wireless networks is collision, resulting from two nodes sending data at the same time over the same transmission medium or channel. Medium access control (MAC) protocols have been developed to assist each node to decide when and how to access the channel. This problem is also known as channel allocation or multiple access problem. The MAC layer is normally considered as a sublayer of the data link layer in the network protocol stack.

MAC protocols have been extensively studied in traditional areas of wireless voice and data communications. Time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA) are MAC protocols that are widely used in modern cellular communication systems [1]. Their basic idea is to avoid interference by scheduling nodes onto different sub-channels that are divided either by time, frequency or orthogonal codes. Since these sub-channels do not interfere with each other, MAC protocols in this group are largely collision-free. We refer to them as scheduled protocols.

Another class of MAC protocols is based on contention. Rather than pre-allocate transmissions, nodes compete for a shared channel, resulting in probabilistic coordination. Collision happens during the contention procedure in such systems. Classical examples of contention-based MAC protocols include ALOHA [2] and carrier sense multiple access (CSMA) [3]. In ALOHA, a node simply transmits a packet when it is generated (pure ALOHA) or at the next available slot (slotted ALOHA). Packets that collide are discarded and will be retransmitted later. In CSMA, a node listens to the channel before transmitting. If it detects a busy channel, it delays access and retries later. The CSMA protocol has been widely studied and extended; today it is the basis of several widely-used standards including IEEE 802.11 [4].

Sensor networks differ from traditional wireless voice or data networks in several ways. First of all, most nodes in sensor networks are likely to be battery powered, and it is often very difficult to change batteries for all the nodes. Second, nodes are often deployed in an ad hoc fashion rather than with careful pre-planning; they must then organize themselves into a communication network. Third, many applications employ large numbers of nodes, and

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node density will vary in different places and times, with both sparse networks and nodes with many neighbors. Finally, most traffic in the network is triggered by sensing events, and it can be extremely bursty. All these characteristics suggest that traditional MAC protocols are not suitable for wireless sensor networks without modifications.

In this paper, we propose a novel robust MAC protocol for WSNs. The proposed MAC protocol, SDMA is based on uniform Latin squares, from which there is a one-to-one map between the space divisions and the time slots. The new scheme relies on sensor node position information and provides sensor nodes access to the wireless communication channel based on their spatial locations.

This paper is organized in the following way. Section II discusses SDMA in detail. Section III briefly overviews uniform Latin squares. The mapping function based on uniform Latin squares is explained in section IV. System model is presented in section V. section VI discusses the multiple power level system. Analysis of results is given in section VII. Finally, section VIII concludes the paper.

2. Space Division Multiple Access

SDMA in wireless sensor networks provides a fair and delay bounded medium access to all nodes and the rate at which the nodes join or depart the network (mobility) does not effect the network organization. SDMA provides a collision-free access to the communication medium for the sensor nodes based on their position in space. Therefore, each sensor node must have real-time position information.

The main feature of SDMA is that the geographical area where the sensor nodes are located is divided into smaller space divisions where there is a one-to-one map between the space divisions and the bandwidth divisions. The bandwidth could be divided according to any multiple access schemes such as TDMA, CDMA, and FDMA. Let us consider the geographical space S and partition it into k space divisions (S_1, S_2,…., S_k) where every space division holds n number of sensor nodes. Moreover, assume that the bandwidth B is also partitioned into k divisions (B_1, B_2,…., B_k) where the divisions could refer to time slots, frequency divisions, or codes. Now consider a one-to-one map such as

$$F : S \rightarrow B$$

that assigns a unique bandwidth division to every space division. Thus, SDMA assigns medium access to the users based on their position.

Every sensor node needs to know its real-time position in the geographical space, and the unique map of its position to the set of bandwidth divisions, F. Therefore, the user requirement is the knowledge of the following:

(i) Position in real-time.
(ii) The one-to-one map from space divisions to bandwidth divisions.

Let us take time slots as bandwidth divisions assigned by SDMA. That is, SDMA provides time division multiple access (TDMA) based on the space position of the users. Consider the map

$$F : S \rightarrow T$$

where T is a time period. Consider a sensor node x that has its position information with respect to the space divisions in real-time denoted by $S_x(t)$. The node x uses the map F to find its time slot, say, T_i. Therefore, the node x can access the communication channel without contention. The sensor nodes do not exchange MAC protocols and still can access the communication channel without data collision. Thus, the bandwidth is used efficiently for data communication. If the time slots are equal intervals, SDMA provides equal bandwidth to all sensor nodes.

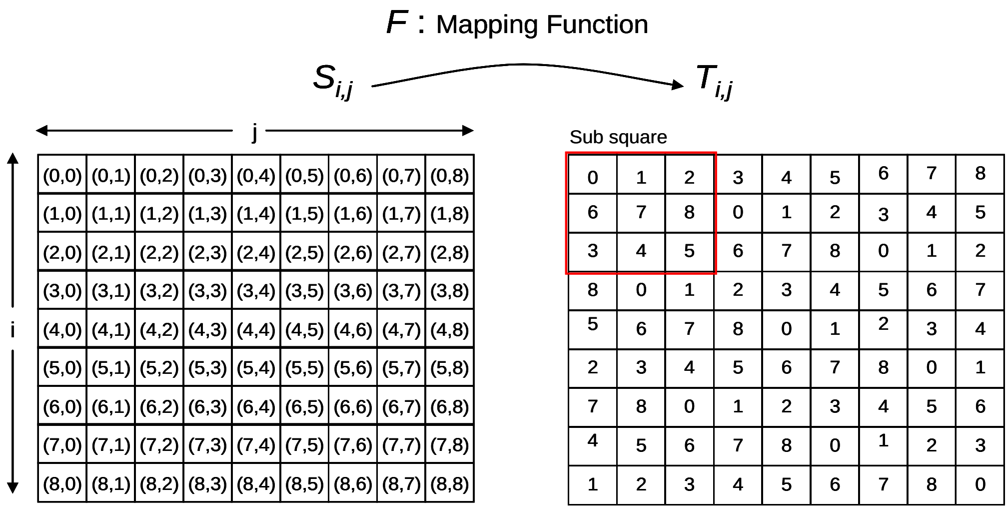
In some applications, sensor nodes move around the sensor field. In this case, their space positions may change in real-time. That is, the position of the sensor node x at time t' may be not the same as its position at time t, $S_x(t') \neq S_x(t)$ when $t' \neq t$. The new position of x maps to a new time slot, say, T_j where $T_j \neq T_i$. In other words, the access time of x varies within a period as it moves. However, the delay is bounded in the sense that every sensor node can access the channel at every period.

3. Uniform Latin Squares

The study of Latin squares provides an environment rich in important results, in unsolved problems and practical applications. The results of such fields are algebra, finite geometrics, coding theory, combinatorial design theory and statistics [5].

A Latin square of order n is an n x n Square composed with symbols from 0 to n - 1 such that no symbol appears more than once in any row or in any column [6]. The rows are numbered from 0 to n- l, top to bottom. The columns are also numbered from 0 to n-l, left to right and are given by the following equation of the classic Latin squares:

$$k = (i + j) \bmod n, \text{ where } 0 \leq i < n, \quad 0 \leq j < n \qquad (1)$$



(0,0)	(0,1)	(0,2)	(0,3)	(0,4)	(0,5)	(0,6)	(0,7)	(0,8)
(1,0)	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	(1,6)	(1,7)	(1,8)
(2,0)	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)	(2,6)	(2,7)	(2,8)
(3,0)	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)	(3,6)	(3,7)	(3,8)
(4,0)	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)	(4,6)	(4,7)	(4,8)
(5,0)	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)	(5,6)	(5,7)	(5,8)
(6,0)	(6,1)	(6,2)	(6,3)	(6,4)	(6,5)	(6,6)	(6,7)	(6,8)
(7,0)	(7,1)	(7,2)	(7,3)	(7,4)	(7,5)	(7,6)	(7,7)	(7,8)
(8,0)	(8,1)	(8,2)	(8,3)	(8,4)	(8,5)	(8,6)	(8,7)	(8,8)

0	1	2	3	4	5	6	7	8
6	7	8	0	1	2	3	4	5
3	4	5	6	7	8	0	1	2
8	0	1	2	3	4	5	6	7
5	6	7	8	0	1	2	3	4
2	3	4	5	6	7	8	0	1
7	8	0	1	2	3	4	5	6
4	5	6	7	8	0	1	2	3
1	2	3	4	5	6	7	8	0

Figure 1. One-to-one map between Space Divisions and Time Slots.

The squares A and B shown below are examples of Latin squares of order 4.

$$B = \begin{bmatrix} 0 & 1 & 2 & 3 \\ 2 & 3 & 0 & 1 \\ 3 & 2 & 1 & 0 \\ 1 & 0 & 3 & 2 \end{bmatrix}$$

A transversal of a Latin square of order n is a set of n cells, no two in a same row, no two in a same column and no two have a same symbol. A diagonal Latin square of order n is a Latin square such that no symbol appears more than once in any of its two main diagonals. A simple construction method is known for' diagonal Latin squares of order n when n is a power of two [6]. The square B shown above is an example of a diagonal Latin square of order 4. Two Latin squares C and D of order n are orthogonal to each other if the set of ordered pairs $CD=\{(c_{ij}, d_{ij}), 0\leq i, j \leq n-1\}$ is equal to the set of all possible ordered pairs (i, j), $0\leq i, j\leq n-1$. The squares C and D shown below are orthogonal to each other.

$$C = \begin{bmatrix} 0 & 1 & 2 \\ 1 & 2 & 0 \\ 2 & 0 & 1 \end{bmatrix} \qquad D = \begin{bmatrix} 0 & 1 & 2 \\ 2 & 0 & 1 \\ 1 & 2 & 0 \end{bmatrix}$$

4. Mapping Function Based on Uniform Latin Squares

As we mentioned earlier, SDMA provides TDMA based on the space position of the sensor nodes. Consider the map:

$$F : S \rightarrow T$$

Where there is a one-to-one map between space divisions and time slots. Now, based on the uniform Latin square, we can design this mapping function that will guarantee contention free channel access to all the sensor nodes. It is clear that a square obtained by the row or column permutation of Latin square is also a Latin square. For a uniform Latin square of order $k = m^2$, where m is any positive integer greater than 1, we can use this following mapping function:

$$F : S_{i,j} \rightarrow T_{i,j} : \left\{ \begin{array}{l} T_{i,j} = \left[(k-m)\cdot i - \left\lfloor \frac{i}{m} \right\rfloor + j \right] \mathrm{mod}(k) + 1. \\ Where \\ 0 \leq i \leq k-1. \\ 0 \leq j \leq k-1. \\ k = m^2, m = 2,3,4... \end{array} \right\}$$

to construct a uniform Latin square and using the (i,j) index to map a space division $S_{i,j}$ to $T_{i,j}$. $\lfloor x \rfloor$ is the floor function of the real integer x that returns the largest integer less than or equal to *x*. Figure 1 illustrates the concept of the one-to-one mapping between the space divisions and the time slots. A sensor node first determines its position using global positioning system (GPS) or any GPS free positioning system such as TPLS [9], then uses the mapping function to map its coordinates to the time slot.

5. System Model

We consider a network with n sensor nodes, uniformly distributed in virtual grids, over a square region with size of (*i, j*) square meters. The square region can be further divided into (*a.a*) deployment areas. We denote each small deployment area as Cluster *C(a,a),* where *Area(C(a,a))* = a^2 . The separation between adjacent nodes is $1/\sqrt{n}$ units. An example of deployment region is shown in Figure 2. Each node can detect events within some distance from it, called *sensing range* with a radius *r(n)*. A pair of nodes *A* and *B* can communicate with each other if the distance between them is less than specified value, where the bound on the communicating distance can be due to power constraints at each node. We let *R(n)* denote the *transmission radius* of a node. Thus, the nodes *A* and *B* can communicate directly with each other if $\|x_A - x_B\| \le R(n)$, where the norm used is the Euclidean norm. Since SDMA provides time division multiple access (TDMA) based on space position of the sensor nodes, we assume that a global clock is available to all the nodes such that slotted transmission can be achieved. Figure 3 shows a typical TDMA frame structure. The channel is divided into n time slots and each time slot contains k minislots. The n slots comprise a frame, which repeats cyclically. The number of slots per cluster, therefore, is bounded by the number of slots in a frame. The number of slots per frame is determined in the system deployment phase. There are N discrete power levels in the system. The value of the power levels and the packet lengths are dynamic. Power level of each packet is chosen independently. The number of minislots is chosen at each power level with the packet length of the corresponding power level. At each power level, packet transmission starts only at the edge of any minisots and each packet contains W symbols. We do not assume slot synchronization between different power levels. If a packet is lost due to collision, it is retransmitted at a later time.

SDMA demands a positioning accuracy that is achievable (and affordable) by all sensor nodes. If the geographical area is divided into very small divisions, the required accuracy may not be achievable. Moreover, when the geographical area is divided into many small divisions but the number of sensor nodes is small, then the bandwidth dedicated to the unoccupied space divisions is wasted. On the other hand, if the space divisions are too large, then

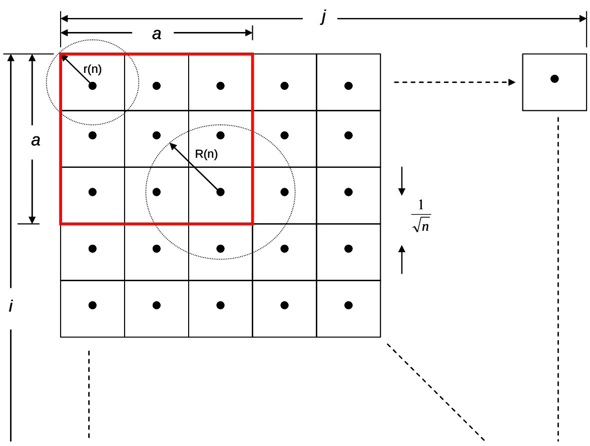


Figure 2. System Model.

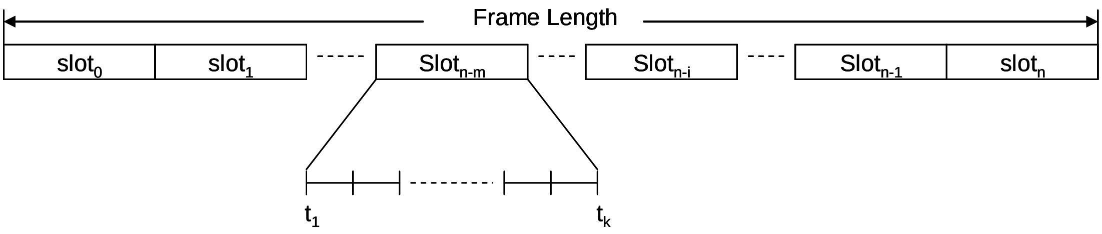


Figure 3 Typical TDMA Frame Structure

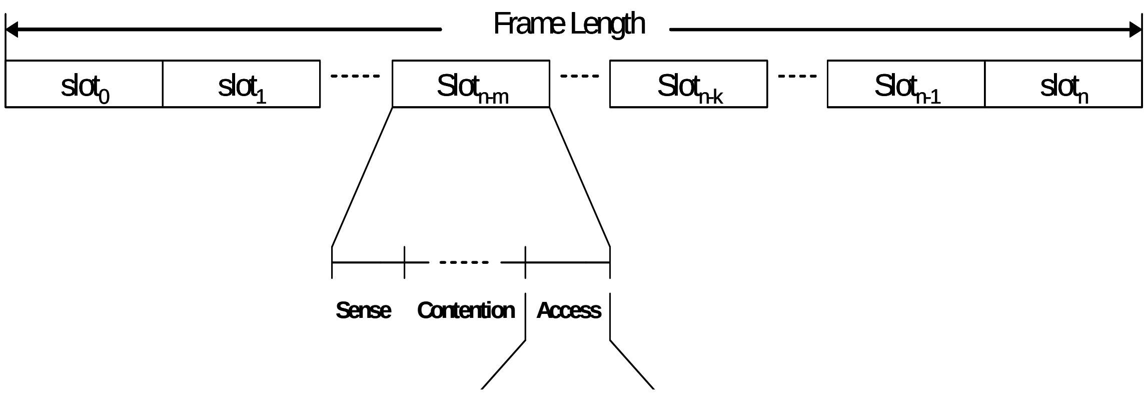


Figure 4. Each time slot is dedicated to multiple sensor nodes that are located at the corresponding space division.

there may be more than one sensor node per division at a time, causing data collisions. We suggest the following scheme which does not need the assumption of one sensor node per space division and allows for a scalable wireless sensor network. Again, we divide the geographical space into a number of space divisions with respect to the available positioning system accuracy and the mean number of nodes in the area. Let m and n denote the number of space divisions and the mean number of nodes, respectively, where we assume $m < n$. Assume that the maximum number of nodes per space division at any given time is equal to or smaller than p. To accommodate more than one node per space division, we redesign the time slots per frame according the frame scheme depicted in Figure 4. At each time slot, the nodes at the corresponding space division contend for the medium access. The specific design at every time slot, sensing time, contention time, access time, and minislots per access time can be determined according to the specific physical layer that is been used and the objectives of the communication network.

The MAC rule at each time slot could be similar to the IEEE 802.11 standard at asynchronous mode. This scheme localizes the contention among a small number of sensor nodes and therefore it drastically reduces the of sensor nodes that contend for the medium access, and decreases the amount of collision. Thus, the bandwidth is utilized more efficiently.

6. Multiple Power Level System

This section presents multiple power level system for SDMA scheme in order to increase the capture probability. The main problem of the proposed SDMA scheme rises when the number of slots per frame is less or equal than 9. Consider Figure 5, after mapping the space divisions to the time slots, nodes B and A are mapped to the same time slot T_1. In this case, if either node A or B transmits its packet using the power level P_i, a collision will occur at either node C or F. However, if both nodes transmit their packets using P_j, collisions are avoided, thus, increasing system throughput. To overcome this problem, we developed self controlled multiple power level system (SCMPL), The aim of the SCMPL is to allow sensor nodes to transmit any packet at a higher probability at the lower power levels which increases the probability of only one packet at the highest power levels. Therefore, the system throughput is increased by augmenting the capture probability. If the traffic load is high, the probability of interfering packets is increases.

Consequently, the transmission probability at the lower power levels increases and the probability of exactly one packet at the highest power levels remains unaltered. As a result, the system is self controlled since it does not need any extra information about the network. Therefore, it is very attractive from an implementation point of view for emerging wireless sensor networks. Extensive comparisons show that the proposed SCMPL demands remarkable throughput performance compared with random multiple power level system (RMPL).

Moreover, the use of multiple power level may increase the system throughput. However, it has its side effect when energy efficiency is considered. Indeed, the use of multiple power levels increases the transmission energy per packet. As energy efficiency is the concern in WSNs, we need to consider the tradeoff between increasing system throughput against improving system energy efficiency. In addition, we observed that for a packet that is sent at a higher power level, the length of the packet can be reduced. Reducing the packet length means reducing the transmission time given the same data rate. By reducing the packet length, we can reduce the chance of packet collision. In this way, we will be able to account for excessive interference from packets at different power levels.

Let us concentrate on the general j^{th} power level Figure 6, j = 1, 2, 3…,N, where N is the lowest power level and 1 is the highest power level ($P_1 > P_2 > \ldots > P_j > \ldots > P_{N-1} > P_N$).

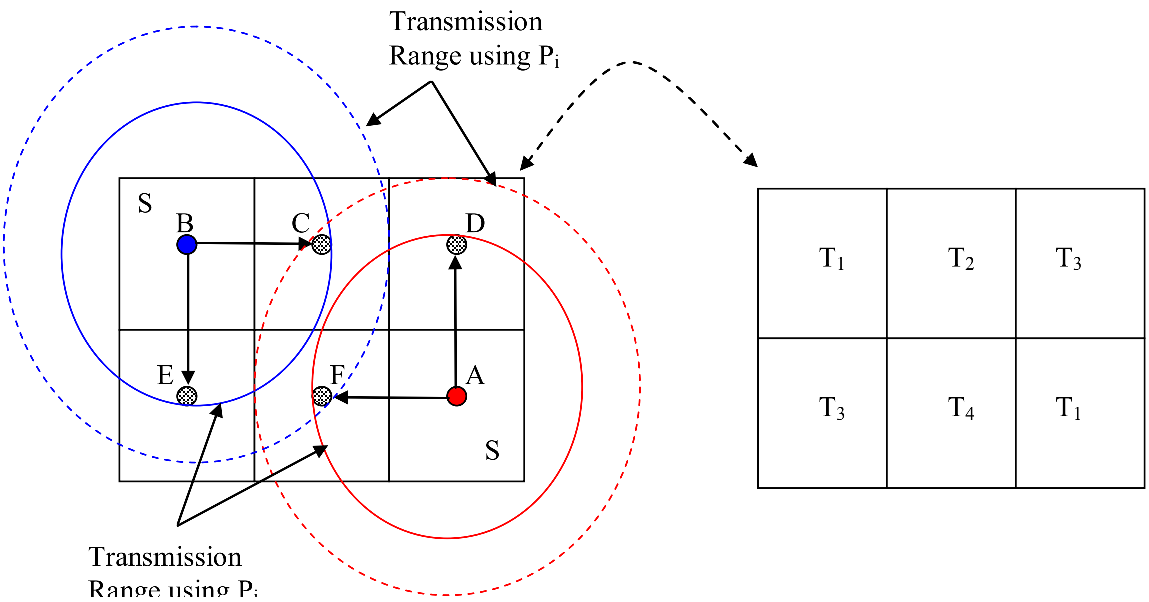


Figure 5. The risk of packets collision when transmitting at high power level

In multiple power level transmission systems, a sensor node can transmit the packet at any power level with a certain probability. Regarding the general j^{th} power level, a packet can be capture by the receiver successfully if and only if all interfering packets in the same time slot are at lower power levels (i.e from (j+1) to N power levels), and exactly one packet is transmitted at the jth power level. Assuming that the jth power level is sufficiently high so that if there is a packet at the (j+1)th power level, a receiver can decode the packet at the j^{th} power level successfully.

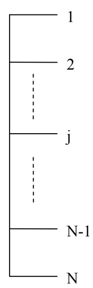


Figure 6 Multiple power levels

Let $P_x[Success|j]$ be the Conditional Probability Mass function of transmitting a packet with the j^{th} power level received successfully, where X (X = RMPL and SCMPL) defines two kinds of transmission probability. The average number of packets transmitted at all N power levels is G packets per time slot. Consequently, $P_x[Success|j]$ can be defined as:

$$\boldsymbol{P_X[Success \mid j] = \sum_{m=0}^{\infty} P[Overlap/m] \times P[Success/all\ m\ packets\ have\ lower\ power\ than\ j]} \quad (2)$$

For any kind of transmission

$$P[Overlap/m] = e^{-G}\frac{G^m}{m!} \quad (3)$$

and

$$\boldsymbol{P[Success/all\ m\ packets\ have\ lower\ power\ than\ j] = \left(\sum_{k=j+1}^{N} P_{X,k}\right)^m} \quad (4)$$

Therefore, we can write

$$P_X[Success \mid j] = \sum_{m=0}^{\infty} e^{-G}\frac{G^m}{m!} \times \left(\sum_{K=j+1}^{N} P_{X,K}\right)^m \quad (5)$$

$$P_X[Success \mid j] = e^{-G}\sum_{m=0}^{\infty} \frac{G^m}{m!} \times \left(\sum_{K=j+1}^{N} P_{X,K}\right)^m \quad (6)$$

$$P_X[Success \mid j] = e^{-G}\sum_{m=0}^{\infty} \frac{\left(G\left(\sum_{K=j+1}^{N} P_{X,K}\right)\right)^m}{m!} \quad (7)$$

Form Taylor Series

$$e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!}$$

Then

$$P_X[Success \mid j] = e^{-G} \times e^{G\left(\sum_{K=j+1}^{N} P_{X,K}\right)} \quad (8)$$

$$P_X[Success \mid j] = e^{-G} \times e^{G\left(1-\sum_{K=1}^{j} P_{X,K}\right)} \quad (9)$$

$$P_X[Success \mid j] = e^{-G-G\left(1-\sum_{K=1}^{j} P_{X,K}\right)} \quad (10)$$

$$P_X[Success \mid j] = e^{-G+G-G\sum_{K=1}^{j} P_{X,K}} \quad (11)$$

$$P_X[Success \mid j] = e^{-G\sum_{K=1}^{j} P_{X,K}} \quad (12)$$

The probability of success of a packet transmitted at all N power levels can be defined form total probability theory as

$$\boldsymbol{P_X[Success] = \sum_{k=1}^{N} [Success \mid j] \times P\begin{bmatrix} probability\ of\ transmitting\ a \\ packet\ to\ the\ j^{th}\ power\ level \end{bmatrix}} \quad (13)$$

$$P_X[Success] = \sum_{j=1}^{N} P_X[Success \mid j] \times P_{X,j} \quad (14)$$

$$P_X[Success] = \sum_{j=1}^{N} P_{X,j} \times e^{\left(-G\sum_{k=1}^{j} P_{X,K}\right)} \quad (15)$$

Finally, the general throughput with the multiple power level approach is

$$S_X = GP_X[Success] \quad (16)$$

$$S_X = G\sum_{j=1}^{N} P_{X,j} \times e^{\left(-G\sum_{k=1}^{j} P_{X,K}\right)} \quad (17)$$

Two different kinds of transmission probabilities are considered next: random multiple power level system (RMPL) and self controlled multiple power level algorithm (SCMPL)

6.1. Random Multiple Power Level System

Considering N discrete power levels $P_1 > P_2 > \ldots > P_j > \ldots > P_{N-1} > P_N$ as shown in Figure 7, each power level is selected by a random choice. Therefore, the probabilities for transmitting at different power levels are equal and given by:

$$\boldsymbol{p_{RMPL} = \frac{1}{N}} \quad (18)$$

This type of transmission probability is well known and defined in [7, 8]. According to the SCMPL which will be defined next, the packet is transmitted at lower power levels with a high probability and at higher power levels with a lower probability. The aforementioned RMPL does not fall in that category. Therefore, we compare the proposed SCMPL with RMPL.

6.2. Self Controlled Multiple Power Level Algorithm.

Consider the N annular system as shown in Figure 7. Any sensor node selects the first power level with a probability proportional to the fractional area of the first innermost annular region. The radius of the first innermost circle is rβ. In the same way, any sensor node transmits a packet at the second power level with fractional probability of the second annular region. The radius of the second annular region is $r\beta^2$. In general, the packet transmission at the jth power level is the fractional probability of the jth inner annular region and the radius of the jth annular region in $r\beta^j$.

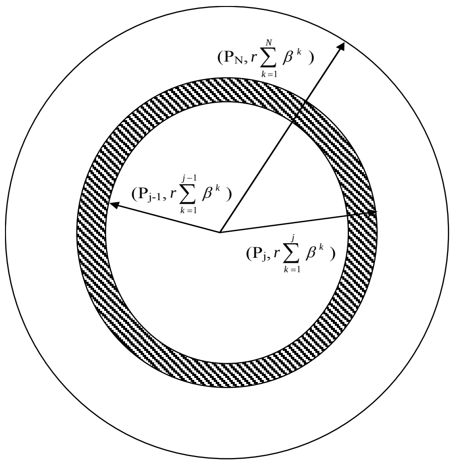


Figure 7 Fractional area of the j[th] annular

$$P_{SCMPL} = \frac{\int_{r\sum_{k=1}^{j-1}\beta^k}^{r\sum_{k=1}^{j}\beta^k} 2\pi y dy}{\pi\left(r\sum_{k=1}^{N}\beta^k\right)^2} \quad (19)$$

$$P_{SCMPL} = \frac{2\pi\left[\frac{y^2}{2}\right]_{r\sum_{k=1}^{j-1}\beta^k}^{r\sum_{k=1}^{j}\beta^k}}{\pi\left(r\sum_{k=1}^{N}\beta^k\right)^2} \quad (20)$$

Using the finite geometric series rule:

$$\sum_{k=1}^{N} a^k = \frac{(1-a^k)}{1-a}$$

and rearranging equation (20), we obtain:

$$p_{SCMPL} = \frac{\beta^j(\beta^j-2)-\beta^{j-1}(\beta^{j-1}-2)}{(1-\beta^N)^2} \quad (21)$$

Therefore, the packet distribution probability at the jth power level is:

$$P_{X,j} = \begin{cases} \dfrac{1}{N} & \text{for X = RMPL} \\[2ex] \dfrac{\beta^j(\beta^j-2)-\beta^{j-1}(\beta^{j-1}-2)}{(1-\beta^N)^2} & \text{for X = SCMPL} \end{cases} \quad (22)$$

and

$$\sum_{k=1}^{j} p_{X,k} = \begin{cases} \dfrac{j}{N} & \text{for X = RMPL} \\[2ex] \dfrac{(\beta^j-2)^2}{(1-\beta^N)^2} & \text{for X = SCMPL} \end{cases} \quad (23)$$

Finally, the throughput for each scheme can be obtained by combining (17), (22), and (23)

$$S_X = G\sum_{j=1}^{N} P_{X,j} \times e^{\left(-G\sum_{k=1}^{j} P_{X,K}\right)} \quad (24)$$

7. Analysis of Results

In this section, computation is conducted to evaluate the performance of the proposed SDMA scheme. First, we evaluate the proposed scheme based on the SCMPL in comparison with RMPL. The performance metrics considered for this evaluation is throughput. . We adopted the conventional assumption that the overall packet arrival pattern, including new arrivals and retransmissions is Poisson. Also, all the parameters described in the system model in section 5 remain the same.

The throughput is measured by the average number of successfully received packets per slot. As can be seen from the Figure 8, the use of multiple power levels can indeed increase the system throughput. However, in multiple power level, a sensor node can transmit packet at any power levels from 1 to N. . In this case, if sensor nodes transmit packets randomly without the knowledge of other sensor nodes, the probability of transmitting more than one packet at the highest power level increases and thus the throughput of the system decreases as shown in Figure 9, rendering the system unstable.

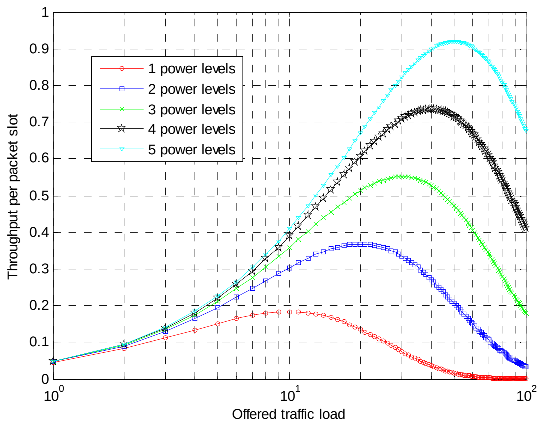


Figure 8 Throughput per packet slot versus offered traffic

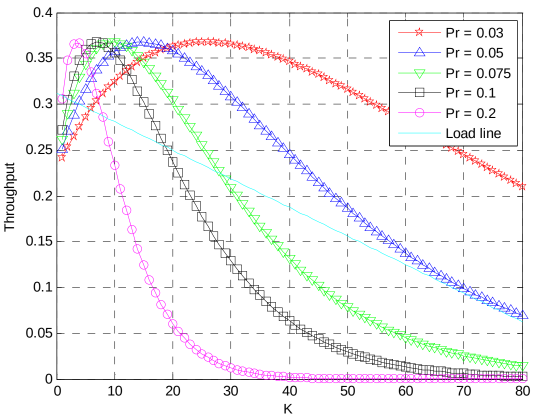


Figure 9 The throughput characteristics for different values of retransmission probability.

Also, the figure depicts the numerical results of the throughput-stability characteristics for different values of retransmission probabilities. The system is stable if the load line intersects the throughput curve exclusively at one point. As can be seen, a stable system can be obtained by decreasing the retransmission probability. Therefore, it is necessary to evaluate the performance of the multiple power level system based on SCMPL versus RMPL.

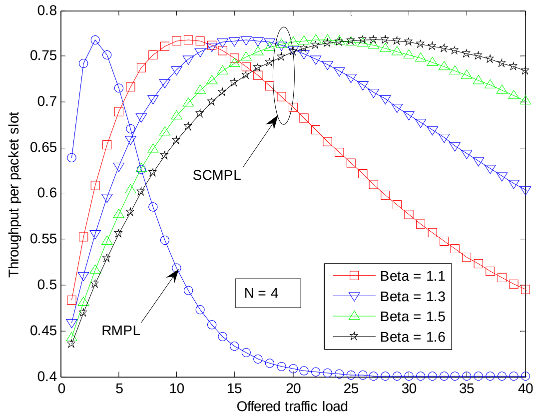


Figure 10 The throughput performance of both SCMPL and RMPL

Figure 10 shows the throughput of the multiple power level system when N = 4 and ß with different values. This is evidence that SCMPL algorithm achieves a higher throughput by using multiple power levels more technically than the RMPL. This figure clarifies that the SCMPL algorithms can provide a higher throughput especially at higher traffic condition. Also, the value of ß has to be increased with increasing retransmission probability to keep the channel stable. Thus, the system is stable with a high transmission probability, but at the expense of a higher average number of retransmission mode sensor nodes.

8. Conclusion

SDMA scheme is an innovative scheme for medium access control in wireless sensor networks. SDMA relies on real-time position information by the sensor nodes and provides a mapping of the sensor node position to a time slot. A new Latin square called a uniform Latin square is introduced to be used as a mapping function to map space divisions to time slots. Using the uniform Latin square, the lime slots per cluster are allocated without any conflict. To reduce co- channel interference, a self control multiple power level algorithm (SCMPL) is proposed. For a given number of power levels, the probability of more than one packet at the highest power levels increases if the traffic load is very high. If the sensor nodes transmit packets at higher power levels with lower probability, the probability of only one packet at the highest power levels increases. Consequently, enhancement of the packet success probability in each slot is achieved, keeping the system stable at a higher traffic loading condition. The rest of the packets fall automatically to lower power levels due to the higher selection probabilities of those power levels. SCMPL algorithm can keep the channel stable with a very high retransmission probability, thus decreasing the average packet delay.

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