Full Communication in a Wireless Sensor Network by Merging Blocks of a Key Predistribution using Reed Solomon Code

Aritra Dhar[1] and Pinaki Sarkar[2]

[1]CSE Department, Gurunanak Institute of Technology, Kolkata-700114, INDIA
aritra.dhar7@gmail.com
[2]Mathematics Department, Jadavpur University, Kolkata-700032, INDIA
pinakisark@gmail.com

Abstract.

Wireless Sensor Networks (WSN) are constraint by the limited resources available to its constituting sensors. Thus the use of public-key cryptographyduring message exchange gets forbidden. One has to invoke symmetric key techniques. This leads to key distribution in the sensors which in itself is a major challenge. Again due to resource constraints, Key Predistrubution (KPD) methods are preferred to other distribution techniques. It requires predistribution of keys in nodes prior to deployment and establishing immediately once deployed. However there are certain weaknesses in various existing KPD schemes. For instance, often it is not guaranteed that any given pair of nodes communicate directly. This leads one to revert to multi-hop communication involving intermediate sensor nodes resulting in increased cost of communication. In this work a key predistribution technique using Reed-Solomon codes is considered which is faced with the above weakness. The authors suggests a novel technique of merging certain number of sensors into blocks ensuring that the blocks have full connectivity amongst themselves. Here the blocks are chosen in such a way that it ensures no intra-node communication. Further this approach improves both time and space complexity of the system.

Keywords:

Communication, Reed-Solomon Codes,Merging blocks, Key Predistribution,Security.

1 Introduction

Wireless Sensor Network (WSN) is a popular type of ad-hoc network where sensor nodes are distributed over a large geographical area. The sensor nodes constituting a WSN communicate with each other and with the base station by radio frequency. Each tiny sensor mainly consists of (i) a wireless transceiver, (ii) a small CPU and (iii) a small battery. All these resources available to be sensors have very limited capacities Inspite of the resource constraint in its basic building blocks, WSNs has several military and civilian applications like detecting and monitoring enemy movement, to detect and characterize chemical, biological, radiological, nuclear, explosive

D.C. Wyld, et al. (Eds): CCSEA 2011, CS & IT 02, pp. 389–400, 2011.
 DOI: 10.5121/csit.2011.1234

materials (CBRNE),monitor traffic movement in city rodes and highway, Due to the critical functionality of WSN, communication between the nodes must be encrypted to make it immune to unauthorized accesses. Considering the architectural design,WSN can be segmented to two classes, viz.:

1. HierarchalWireless Sensor Network(HWSN): In this HWSN, there is a predefined hierarchy in the participating sensor nodes. There are three levels in the HWSN model they are- the base station, the cluster head and the sensor node. There are three types of communication possible in HWSN. They are:

   – Unicast - sensor node to sensor node,
   – Multicast - group wise communication and
   – Broadcast base station to sensor nodes.

2. Distributed Wireless Sensor Network (DWSN): In case of DWSN there is no fixed type of architecture in the sensor nodes. The topology is unknown before the deployment. The mode of communication is always Unicast in this case.

1.1 RelatedWorks and our contributions

Key predistribution in sensor networks was first considered by Eschenaur and Gligor [4]. In their work, every key is associated with an unique *key identifier*. To form the *Key rings* of the sensors, keys are *randomly* drawn from the *key pool*. *Key establishment* is also random. Such method of key predistributuion is *probabilistic* in the sense that both key distribution and establishment is done randomly. Many such *probabilistic key predistribution* schemes have been well studied and presented in a survey report published in 2005 by C¸ ampete and Yenner [2].

For the above probabilistic approach, *shared key establishment* and *path key discovery* can become very difficult. Lee and Stinson proposed two schemes [5–7] where they have adopted combinatorial techniques for predistribuion and later establishment of keys. Their works also suggests that both *shared key establishment* and *path key discovery* can be better achieved by the suggested *deterministic approach*. Some other deterministic schemes have been proposed by Ruj and Roy using various combinatorial designs like PBIBD and Transversal Designs in their works [8, 9] respectively. Very recently unique factorization of polynomials over Finite Fields has been invoked by Sarkar and Chowdhury [15] to give a KPD scheme while Bag and Ruj [1] utilizes Affine plane geometry over Finite field for similar purpose.

Hybrid key predistribution scheme by Merging block technique in WSN was first proposed by Chakarabarti et. al. [3]. Their merging block technique was based on transversal design proposed by Lee and Stinson [5, 6]. Transversal design proposed by Lee and Stinson [5, 6] has a major drawback i.e., the absence of full communication hence intermediate nodes were incorporated which increase overall system overhead. Here nodes were merged in random fashion to get new nodes. The objective was to increase number of common keys between any two given new (merged) nodes and achieve full communication within the system.

There are other schemes with similar drawback. For instance a key pre-distribution scheme using Reed-Solomon code with parameters (n, qk, d, q) was proposed by Ruj and Roy[10]. The authors of [10] has established the number of common key between any two given nodes are at most k−1.

Thus in their scheme with high probability direct communication may not be possible between given pair of nodes.

In this paper we apply the merging block scheme on the nodes in WSN where key-predistribuion is done by Reed-Solomon code. Using this merging block technique one can observe the increment of common keys between any two given merged block hence increase the probability of direct communication. This greatly enhance system efficiency.

Of course inability of direct communication is not the only deficiency of Ruj & Roy's scheme in [10]. These scheme like most KPD scheme is faced with a serius problem of *selective node attack* during key establishment phase. In their recently published pioneering work, Sarkar et al. [11] has develop a novel black box technique which ensure security against this form of attack. They have theoretically established that their method enhances security of the overall messaging immensely. Of late this technique have been used to by Sarkar & Saha in [12], Bag, Saha & Sarkar in [13, 14] to improved schemes proposed in [8, 1, 5–7] respectively.

2 Preliminaries

This section is devoted to describing various preliminary aspects that we shall use while designing our key predistribution scheme. As described earlier, we shall develop our merging block design based on a KPD scheme proposed by Ruj and Roy [10] that uses Reed–Solomon codes. Hence after briefly stating the basics of BIBD designs in section 2.1, we move on to describing their scheme in section 2.2 and then point out a potential weakness in their proposed scheme in section 2.3.

2.1 Combinatorial design: BIBD

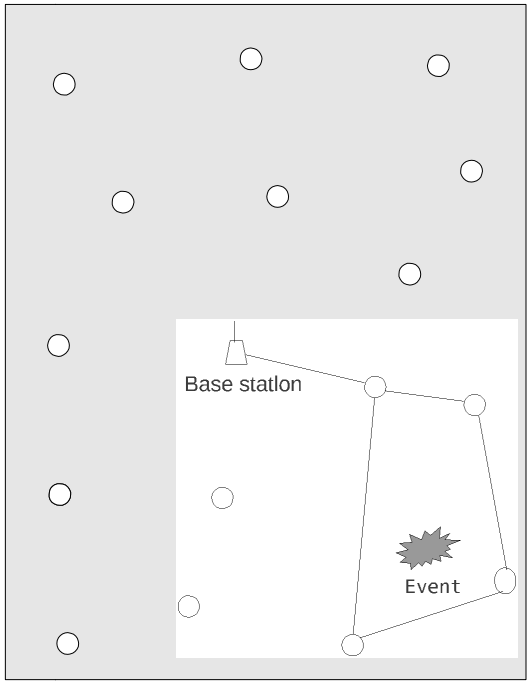
Detailed explanation of Balanced Incomplete Block Designs (BIBD can be found in combinatorics books like the one written by Stinson [16]. Such designs are useful for constructing key predistribution (KPD) schemes in Wireless Sensor Networks (WSN). A brief outline is presented here. Let $\mathbb{X}$ be a set and $\mathbb{A}$ be the finite set of subsets (also known as block) of $\mathbb{X}$. The pair $(\mathbb{X}, \mathbb{A})$ is known as s *set system* or *design*. The degree of a point $x \in \mathbb{X}$ is the number of subsets containing the point x. $(\mathbb{X}, \mathbb{A})$ is said to be uniform of rank k if all its subsets i.e. the blocks has same size k. If all points have same degree r then $(\mathbb{X}, \mathbb{A})$ is said to be regular of degree r. A regular and uniform set system is known as a $(v, b, r, k) - 1$ design where $|\mathbb{X}| = v, |\mathbb{A}| = b$, r is the degree and k is the rank. The condition $bk = vr$ (refer [5, 6] is necessary and sufficient for existence of such a system. If any two distinct block intersect in *zero* or *one* point then $(v, b, r, k) - 1$ is known as a (v, b, r, k) design.

2.2 Key Predistribution using Reed Solomon code

Consider a (n, q^k, d, q) Reed Solomon code having alphabet in the finite field F_q for q > 2. The length of the code is n = q − 1, distance is d = n− k +1 and dimension is k. The number of codeword is M = q^k. When this code is mapped to a Wireless Sensor Network, number of node in the network is q^k each having q − 1 number of keys. The number of common keys between any two nodes is n-d = k -1. For any codeword x = (a_1 , a_2 , . . . , a_n), the keys assigned to the node x

are $(a_1, 1), (a_2, 2), \ldots, (a_n, n)$. The key pool consists of qn number of keys $\{(a_i, i) : a_i \in F_q, i = 1, 2, \ldots, n\}$. Let F_q be a finite field of $q > 2$ elements. Let ρ be the set of polynomials over F_q of degree at most $k-1$. Thus $|\rho| = q^k$ Let $F^* = \{\alpha_1, \alpha_2, \ldots, \alpha_{q-1}\}$ be the set of non-zero elements of F_q. For each polynomial $\rho_i(x) \in \rho$, it is defined $c_{pi} = (\rho_i(\alpha_1), \rho_i(\alpha_2), \ldots, \rho_i(\alpha_{q-1}))$ to be the i-th codeword of length $q-1$. It is defined that $C = \{c_{pi} : p_i(x) \in \rho\}$. so, C is a Reed Solomon code.

A sample network having 16 nodes is present in figure 1



Wireless Sensor Network based on key predistribution using Reed Solomon code with q=4, k=2, merging block not applied

Fig. 1. WSN based on KPD using Reed Solomon codes where q = 4, k = 2

2.3 Weakness : Motivation of our work

Among several other weaknesses we figure out a potential weak point i.e. lack of full communication within the above mentioned scheme using Reed Solomon codes for key predistribution. This clearly indicates that there are several possibilities that direct communication between any pair of given node is not possible, which may lead to increased system overhead.

3 Remedial Strategy : Merging block in combinatorial design

Merging block technique is a novel trick to overcome the drawbacks imposed by the KPD using Reed Solomon code. In this merging block technique several blocks are randomly merged together to form a new node. Here the model is flexible enough that one can mention the number of blocks to merged together randomly (here denoted by z). This technique causes increment of keys in newly formed node, which ensures increment of probability that any given pair nodes can communicate directly. Details of technical results are discussed bellow.

This KPD design prosed in [10] can be easily checked to be a (v, b, r, k) – 1 BIBD having configuration v = rk and b = q2. Here z many blocks are merged together to form a node where

1. Number of sensor nodes $N = \lfloor \frac{b}{z} \rfloor$
2. Probability that any two nodes share no common key is $(1 - p_1)^{z^2}$ where $p_1 = \frac{\sum_{i=1}^{k-1} (-1)^{i-1} q^i \binom{q^{k-1}}{2} \binom{q-1}{i}}{\binom{q^k}{2}}$
3. The expected number of keys shared between two nodes is $z^2 p_1$
4. Each node will contain M many distinct keys, where $zk - \binom{z}{2} \leq M \leq zk$. The average value of M is $\hat{M} = zk - \binom{z}{2})p_1$.
5. The expected number of links in the merged system is $\hat{L} = (\binom{b}{2} - \lfloor \frac{b}{z} \rfloor \binom{z}{2})p_1 - bk(modz)$
6. The key will be present in Q many nodes where $\lceil \frac{r}{z} \rceil \leq Q \leq r$. The average value of Q is $\hat{Q} = \frac{1}{kr}(\lfloor \frac{b}{z} \rfloor)(zk - \binom{z}{2}p_1$

In this merging block technique we use a probabilistic i.e. a random merging technique. This approach mainly involves two steps

1. First the key predistribution is done using Reed-Solomon code
2. Then randomly some number of nodes (usually this number is denoted with z) are merged together which makes new nodes.

After the blocks are merged, in a newly merged node there may be several repeating keys. This repeating keys indicate the possibility that intra-node communication may happen. In this random merging approach, one can't ensure that the nodes that are being merged will not share a common key. To eliminate the possibility of intra-node communication, one trick is to take all the keys once while merging. As such we can make use of a heuristic suggested by Chakraborti et. al [3, section 4] to address this issue.

A typical picture of merging block design corresponding to network of figure 1 on 16 nodes with z = 4 is given in figure 2.

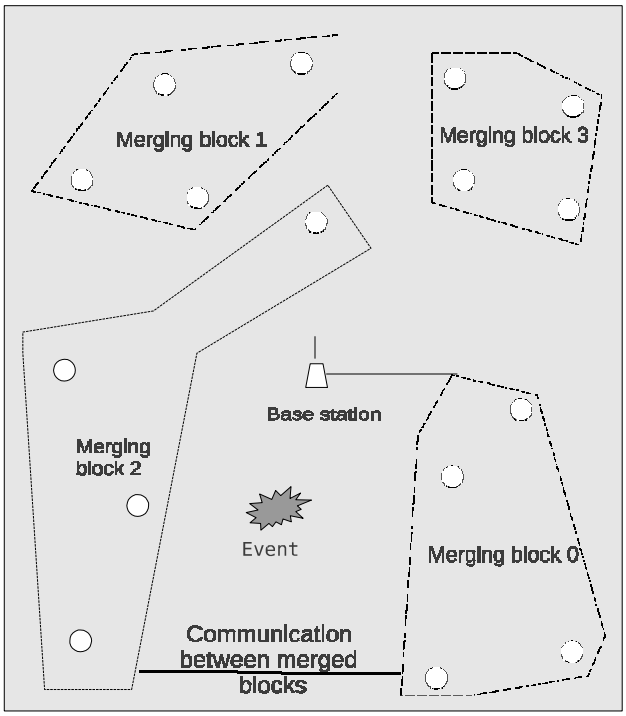


Fig. 2. Same WSN using merging block over Reed Solomon code where q = 4, k = 2, z = 4.

4 Key establishment : Merged block formation

Here blocks are merged in randomizedmanner. Let array node[0 : q^k −1] denotes the array of node id and array_ key[0 : q^k − 1][0 : q − 1] be the array containing all keys of every node.

Start of algorithm.
Take a value z (the no of nodes to merge together to form a new node).
Calculate $N := \lfloor \frac{q^k}{z} \rfloor$.
Take a new array array node random[0 : $q^k - 1$].
Randomize elements of array node[0 : $q^k - 1$] array node random[0 : $q^k - 1$] := array node [0 : $q^k - 1$].
Take a new array array node merge[0 : N][0 : z] take z number of elements from array node random [0 : $q^k - 1$] and store it to array nodemerge[0 :N][0 : z].
if Key from the array array key[0 : $q^k - 1$][0 : $q - 1$] is not present in array_ key_ merge[0 : N][0 : z][0 : $q - 1$] **then**
  Find the keys of the nodes in array node merge[0 : N][0 : z] from the
  array array key[0 : $q^k - 1$][0 : $q - 1$] and store it to to a new array
  array key merge[0 : N][0 : $(q - 1) * z$].
else
  Skip it and move to next key.
end if
The array array key merge[0 : N][0 : $(q - 1) * z$] contain keys of all merged block where no intra-node common key is present.
End of algorithm.

5 Communication

After the blocks are merged, communication between new nodes takes place. Here the Reed-Solomon code is taken as (n, q^k, d, q). The number of common key between any two given nodes at most k−1, i.e., varies from 0 to k−1.When the sensors are merged to form big blocks of z many sensors each, number of common keys between any pair of given nodes increases which greatly increases probability of direct communication between any pair of given nodes. The communication testing algorithm between any pair of nodes is discussed bellow.

Start of algorithm.
Take input id1 and id2 which denotes the node id of a pair of nodes.
Initialize flag as flag = 0.
for i=0:(q-1)*z **do**
 for j=0:(q-1)*z **do**
  if array key merge[id1][i] = array key merge[id2][j] **then**
   flag := flag + 1
  end if
  end for
end for
end for
if flag! = 0 **then**

Direct communication possible.
else
Direct communication not possible
end if
End of algorithm.

6 Communication Probability

The term *Communication probability* denoted by ρ_c of the network is the probability that two nodes are connected. We know that total number of nodes in the network is q^k and each node contains $q-1$ no of keys. So, in the network total $\binom{q^k}{2}$ links are possible. So, we can state that:

$$\rho_c = \frac{Number\ of\ links\ present\ in\ the\ network}{Total\ number\ of\ links\ in\ the\ network}$$

From Ruj and Roy we get this value as

$$\rho_c = \frac{\sum_{i=1}^{k-1}(-1)^{i-1}q^i\binom{q^{k-1}}{2}\binom{q-1}{i}}{\binom{q^k}{2}}$$

7 Resilience

Under adversarial situation, one or more numbers of sensor nodes may get compromised. In that case, all the keys in the node(s) get exposed. They can't be used in the secret communication any longer. Links which are connected by those exposed keys will be broken.When communication links are broken, communication may still exists using alternative paths. Now, another situation may takes place. Let there is node which have all keys compromised. Then the node will get *disconnected*. Node disconnection is a fatal situation as there is no way to communicate with the disconnected node. After the nodes get compromised, one has to calculate the proportion of links broken i.e. the links can not be used any further. This proportion is denoted by E(s). Thus,

$$E(s) = \frac{Numbers\ of\ links\ disconnected\ when\ s\ nodes\ are\ compromised}{Total\ number\ of\ links\ before\ compromise}$$

From the paper of D. Chakrabarti et al., in merging block technique the calculation of E(s) is as bellow.

$$E(s) = \frac{\sum_{i=1}^{z^2} \frac{\binom{\gamma}{i}}{\binom{q(q-1)}{i}} \binom{z^2}{i} p_1^i (1-p_1)^{z^2-i}}{1-(1-p_1)^{z^2-i}} \text{ where } \gamma = sz(k - \frac{(sz-1)p_1}{2})$$

7.1 Calculation of E(s)

Let N_1 & N_2 be any 2 given merged nodes. Consider two events E & F as follows:

1. E: N_1 and N_2 are disconnected after the failure of s number of nodes,
2. F: N_1 and N_2 were connected before the failure of those s nodes.

Then we can clearly see that

$$E(s) = P(E|F) = \frac{P(E \cap F)}{P(F)}$$

Now let X be a random variabledenotingthe number of common keys between N_1 and N_2. Thus we may assume that X follows $B(z^2 p_1)$, i.e. it follows Binomial distribution in accordance to the assumption made in Chakrabarti et. al. [3, section 3]. Thus,

$$P(F) = P(X > 1) = 1 - P(X = 0) = 1 - (1-p_1)^2$$

Next we can consider two events:

1. E_{1i} : i number of keys (shared between N_1 and N_2) are revealed consequent upon the failure of s nodes,
2. E_{2i} : inumber of keys are shared between N_1 and N_2.

Let $E_i = E_{1i} \cap E_{2i}$ for $i = 1, 2, \ldots, z^2$. So, $E_i \cap E_j = \phi$ for $0 \leq i \neq j \leq z^2$. As $E \cap F = \bigcup_{i=1}^{z^2} z^2$, we have $P(E \cap F) = P(\bigcup_{i=1}^{z^2} E_i) = \sum_{i=1}^{z^2} p(E_i) = \sum_{i=1}^{z^2} P(E_{1i}|E_{2i})P(E_{2i})$ and $P(E_{2i}) = \binom{z^2}{i} p_1^i (1-p_1)^{z^2-i}$.

As in Chakrabarti et. al.[3, section 3.2] we estimate $P(E_{1i}|E_{2i})$ by hypergeometric distribution. In this merging block technique the size of the key pool is $q(q-1)$. Letγ denotes the number of revealed distinct keys in a node then

$$\gamma = sz(k - \frac{(sz-1)p_1}{2}).$$

So, $P(E|F) = \frac{\binom{\gamma}{i}}{\binom{q(q-1)}{i}}$ Finally we can get the value of $E(s)$ or $E(s)$. Experimental results are being presented in section 8.

8 Experimental Results

Simulation results for E(s) are presented in table 1 and table 2 compares our results with Ruj & Roy [10] where k = 2 is assumed for a network with N = 2401 nodes. Thus in our case we take N = 2550 nodes. In both cases we have assumed s = 10 nodes have been captured. Their communication probability $\rho_c = p_1$ = the expected number of keys for a given pair of nodes. In the tables 'RS' means Reed-Solomon scheme that has been presented in [10] while 'MB' means the present scheme. In the experiment we considered q = 49. So, total number of nodes in the network is $49^2 = 2401$. Now z = 4 i.e 4 nodes are merged together to form a new merged node. This renders the following scheme.

1. In this case number of merged sensor nodes in the network is $\lfloor \frac{2401}{4} \rfloor = 600$.
2. Probability that two nodes do not shares a common key is 4.29×10^{-23}.
3. Number of keys shared between two nodes are either 0 or 1 (as here $k = 2$ is considered).
4. Each node will contain $\hat{M} = 4 \times 48 - \binom{4}{2}\frac{48}{50} = 186$
5. $E(10) = 0.3164$ and $E(5) = 0.2109$

N	S=3	S=4	S=5	S=7	S=8	S=9	S=10
600	S=0.1697	0.1932	0.2109	0.2527	0.2715	0.2931	0.3164
2550	0.0657	.08374	0.1024	0.140	0.1592	0.1808	0.1997

Table 1. Simulation results for E(s) for N = 600, 2550 as *s=number of nodes captured* varies

Comparison of our design with RS design of [10]	Merging Block (MB) design over RS design of [10]	Reed–Solomon code (RS) design as in [10]
Number of nodes in the network (N)	2550	2401
Number of keys per node	394	48
Communication probability	$1-(1-\frac{100}{102})^{16} \approx 1$	0.52
$E(s)$ for $s = 10$	18656	19996

Table 2. Comparative results for $E(s)$ between our scheme and RS scheme in [10] having about $N = 2400$ nodes with $s = 10$ node capture.

9 Conclusion

In this paper a block merging technique is presented which is applied on key pre distribution strategy using Reed Solomon code. Key pre distribution using reed Solomon code has several drawbacks. So, in several situations direct communication is not possible when number of common keys between two given node is 0. This causes indirect connection or hopping using a intermediate node which increases system overhead. The merging block scheme in this paper resolves this performance overhead greatly by increasing number of common keys between any two given merged nodes while eliminating intra-node communication by reducing intra-node common keys. Here in this paper the main goal is to achieve full communications within the network keeping security intact if in some case some nodes get compromised. This block merging strategy provides a very robust network ensuring full communication.

10 Future Work

In thismerging block technique on *Reed Solomon* code is purely randomized.Whenever the blocks are merged (where z is the number of nodes to merged together to form a new node) it is impossible to determine participating blocks in a particular merged node (or block). So, the control over this kind of model is pretty low. Moreover this whole merging is done during key establishment. So, from the system administrator's point of view, this can be a fatal situation. This only can be resolved by a *deterministic* merging block technique. Because in deterministic approach only those nodes are included in the newly formed node such that it generates no intra-node common key. So, it can be clearly find out that deterministic approach is only the way to tackle this minimized controlling factor.

Another future aspect of this randomized merging block technique is to tackle the primitive requirement of Wireless Sensor Network (WSN) i.e. to reduced E(s) (mentioned earlier in this paper) which improves resilient factor. In this probabilities merging block technique as the number of common keys between any given pair of nodes is increased so there is a high chance of intra node communication. So a better took is desirable to decrease the E(s) factor. As such if the blocks can be merge deterministically prior to deployment, then we can think of applying a novel black box scheme suggested recently by Sarkar et. al. [11] to the merged block design and obtain much better resiliency.

Other than this, its is important to look KPD having full connectivity, high resiliency and is equally scalable. In regards some Algebraic, Combinatorial or other Mathematical techniques may be useful as has been proposed by Sarkar and Chowdhury in [15] and Bag and Ruj in [1].

Acknowledgement

We would like to heartily thank Ms. Amrita Saha, IIT, Bomay for discussion various aspects of the paper. A special word of appreciation goes to Prof. Subhamoy Maitra, ISI, Kolkata for motivating us to use their random block idea in the present case.

References

1. S. Bag and S. Ruj. Key Distribution in Wireless Sensor Networks using Finite Affine Plane. *IEEE Computer Society AINA-2011*, pp. 436-442, 2011.
2. S. A. C¸ amtepe and B. Yener, Key distribution mechanisms for wireless sensor networks:A survey 2005. Technical Report, TR-05-07 Rensselaer Polytechnic Institute, Computer Science Department, March 2005.
3. D. Chakrabarti, S. Maitra and B. Roy, A key pre-distribution scheme for wireless sensor networks: merging blocks in combinatorial design, *International Journal of Information Security*, vol. 5, no. 2, pp. 105–114, 2006.
4. L. Eschenauer and V. D. Gligor, A key-management scheme for distributed sensor networks, *ACM Conference on Computer and Communications Security*, pp. 41–47., 2002
5. J. Y. Lee and D. R. Stinson, Deterministic key predistribution schemes for distributed sensor networks, *Selected Areas in Cryptography*, ser. Lecture Notes in Computer Science, pp. 294–307, Springer, 2004.

6. J. Y. Lee and D. R. Stinson, A combinatorial approach to key predistribution for distributed sensor networks, *IEEE Wireless Communications and Networking Conference, WCNC 2005*, New Orleans, LA, USA, 2005.

7. J. Y. Lee and D. R. Stinson, On the construction of practical key predistribution schemes for distributed sensor networks using combinatorial designs, *ACM Trans. Inf. Syst. Secur.*, 11(2), 2008.

8. S. Ruj and B. Roy, Key predistribution using partially balanced designs in wireless sensor networks, *ISPA 2007*, ser. Lecture Notes in Computer Science, Springer, Heidelberg, pp. 431–445, 2007.

9. S. Ruj and B. Roy, Revisiting key predistribution using transversal designs for a grid-based deployment scheme, *International Journal of Distributed Sensor Networks*, IJDSN 5(6), pp:660–674, 2009.

10. S. Ruj and B. Roy, Key Predistribution Schemes Using Codes in Wireless Sensor Networks, *Inscrypt 2008, LNCS 5487, Springer-Verlag Berlin Heidelberg.*, pp. 275–288, 2009.

11. P. Sarkar, A. Saha and M. U. Chowdhury. Secure Connectivity Model in Wireless Sensor Networks Using First Order Reed-Muller Codes, *MASS 2010*, pp. 507–512, 2010.

12. P. Sarkar and A. Saha. Secure Connectivity Model in Wireless Sensor Networks Using First Order Reed-Muller Codes, *MASS 2010*, pp. 507–512, 2010.

13. S. Bag, A. Saha and P. Sarkar. Highly Resilient Communication Using Affine Planes For Key Predistribution And Reed Muller Codes For Connectivity InWireless Sensor Network, *The Third International Conference on Wireless & Mobile Networks (WiMo-2011)*, to be published, 2011.

14. S. Bag, A. Saha and P. Sarkar. Highly Resilient Key Predistribution Scheme Using Transversal Designs And Reed Muller Codes For Wireless Sensor Network, *The Fourth International Conference on Network Security & Applications (CNSA-2011)*, to be published, 2011.

15. P. Sarkar and M. U. Chowdhury. Key Predistribution Scheme Using Finite Fields And Reed Muller Codes, *Accepted in SNPD 2011. Recommended for publication in 'Springers Studies in Computational Science'*, Springer, 2011.

16. D. R. Stinson Combinatorial Designs: Constructions and Analysis, *Springer-Verlag, New York*, 2003.