ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

Volume 3, Special Issue 3, March 2014

2014 International Conference on Innovations in Engineering and Technology (ICIET'14)
On 21st & 22nd March Organized by

K.L.N. College of Engineering, Madurai, Tamil Nadu, India

Enhancement of Lifetime Using Duty Cycle and Network Encoding In Wireless Sensor Network

Revathe.B, Saranraj Ambeth.V, Tamizharasan.P.S

M.A.M College Of Engineering, Tamilnadu, India

ABSTRACT— The fundamental challenge in design of wireless sensor network is to enhance the network lifetime. Many factors are taken into account for the maximization of life time of wireless sensor networks, such as minimizing the power consumption, low cost operation, optimal routing algorithms, forwarding of residual power to every node to avoid the abbreviating of power in nodes, using improved version of protocols and also communication models. It investigate the lifetime increase in wireless sensor networks to avoid difficulties in network such as traffic flow, bottle neck zone creation, loss of data. It can be solved by using cope algorithm. It consists of duty cycle and network encoding method. By using these methods the bottleneck zone can be avoided. The duty cycle which is used for reduce the node counts and network coding which is used for reduce the path count. If the path count and node count is reduced bottleneck zone is avoided near the sink node, then the network lifetime can be increased in WSN. Duty cycle, network coding and the combination of duty cycle and network coding are implemented in this proposal. Energy efficiency of the bottleneck zone increases because more volume of data will be transmitted to the Sink with the same number of transmissions. This in-turn improves the overall lifetime of the network. Packet delivery ratio and packet latency are the two important metrics to improve the performance of the network lifetime.

KEYWORDS— Duty Cycle, Network Encoding, Packet Latency,Packet Delivery Latency

I.INTRODUCTION

Wireless Sensor systems (WSNs) comprise of autonomous sensor nodes that can be established for monitoring unattainable localities, such as, glaciers, forest fires, deserts, deep seas etc. Sensor nodes are usually equipped with a wireless transceiver, a micro controller, a recollection unit, and a set of transducers utilizing which they can come by and method facts and figures from the established regions. The nodes can self coordinate themselves to form a multi-hop network and convey the facts and figures to a go under. In an energy constraint WSN, each sensor node has restricted electric battery power for which enhancement of network lifetime becomes a major dispute. In a usual WSN, the mesh traffic converges at the Sink node S (Fig. 1). There is an important allowance of facts and figures flow beside the go under. The area beside the Sink is renowned as the bottleneck zone. Hefty traffic burden imposes on the sensor nodes beside the Sink node.

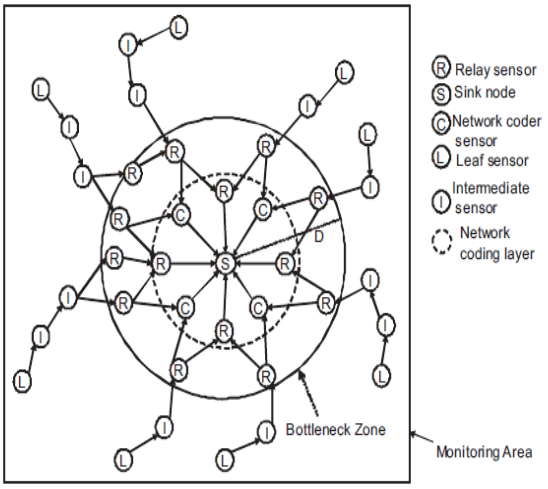

Fig. 1 Traffic flow, Bottle neck zone and role of sensors in WSN.

The nodes in the bottleneck zone deplete their energy very rapidly, referred as power aperture difficulty in WSN. Malfunction of such nodes inside the bottleneck zone leads to wastage of mesh energy and decrease of mesh reliability. The bottleneck zone needs special attention for decrease of traffic which advances the mesh lifetime of the entire WSN. The all-node-active status is not practical for power constraint WSN. The sensor nodes save power by swapping between hardworking and dormant (i.e. sleep) states. The ratio between the time throughout which a sensor node is in active state and the total time of active/dormant states is called obligation cycle.

The duty cycle counts on the node density of the monitored area for better treatment and connectivity. Although it requires added data exchange to disseminates the active/sleep schedule of each nodes. The random duty-cycled WSNs are simple to design as no additional overhead is needed. In this work, the mainly aim is to gain certain analytical comprehending on the upper-bound of the network lifetime[5] thus, the random duty cycle founded WSN has been considered for its simplicity in conceive. Expressly, the difficulty of reduction of traffic in the bottleneck zone has been considered. The upper bound on the lifetime has been studied in a preceding work. However, the top compelled is not intended for sensor nodes with hardworking and dormant states. In our work, the top bound on the network lifetime has been derived for obligation cycle founded WSN founded on. Furthermore, energy effective bandwidth utilization designs in the bottleneck zone are helpful to reduce the additional burden on the sensor nodes. The mesh cipher method improves the capability of a data mesh with better utilization of bandwidth. In a multi-hop communication with network cipher, the intermediate nodes of a mesh can appropriately encode the incoming facts and figures packets before forwarding the coded packets to the next node. The mesh cipher method also improves reliability of the mesh.

In this work, a network cipher founded communication paradigm in the bottleneck zone has been suggested to reduce the traffic burden which enhances the mesh lifetime. The major assistance of this work can be summarized as pursues:

- Estimation of top bounds of the network lifetime through bottleneck zone investigation in (a) random duty cycled WSN (b) non-duty cycled WSN utilizing mesh coding in the bottleneck zone (c) random duty-cycled WSN utilizing mesh cipher in the bottleneck zone. The reason is that lifetime upper bounds permit on the conceive of sophisticated power effective protocols.
- It has been shown that the duty cycle and network cipher techniques can be integrated to utilize the mesh assets effectively. The power utilization in the bottleneck zone has been decreased to improve the lifetime of the general WSN.
- Replication have been conveyed out to show the efficacy of the suggested approach in periods of network lifetime, packet consignment ratio and packet latency.

A. Network Coding

Network coding is a method which allows the intermediate nodes to encode facts and figures packets obtained from its neighboring nodes in a mesh. The encoding[7] and decoding procedures[8] of linear mesh cipher are recounted underneath. Encipher operation: A node, that likes to transmit encoded packets, selects a sequence of coefficients q = (q1, q2, ..., qn), called encoding vector, from GF(2s). A set of n packets Gi(i = 1, 2, 3, 4, ..., n) that are obtained at a node are linearly encoded into a lone yield packet. The yield encoded packet is granted by

$$Y=\sum_{i=1}^{n} qiGi,\ qi \in GF(2^{s}) \tag{1}$$

The coded packets are transmitted with the n coefficients in the network. The encoding vector is utilized at the receiver to decode the encoded facts and figures packets.

Decoding operation are the original packets from the received coded packets. The encoding vector q is obtained by the receiver sensor nodes with the encoded data. Let, a set (q^{1}, Y^{1})…… (q^{m}, Y^{m}) has been obtained by a node. The emblems Y^{j} and q^{j} denote the information emblem and the coding vector for the jth obtained package respectively. A node solves the following set of linear formulas (2) with m formulas and n unknowns for decoding procedure.

$$Y^{j} = \sum_{i=1}^{n} qi\,j\ Gi,\ j= 1,\ldots, m \tag{2}$$

At smallest n linearly independent coded packets should be received by the recipients for correct decode of the initial packets. The only unidentified, Gi, comprises the initial packets that are conveyed in the mesh. The n number of initial packets can be retrieved by explaining the linear scheme in equation (2) after getting n linearly independent packets. The XOR mesh cipher, an exceptional case of linear mesh coding [9], has been utilized in this work. The coded packets that are conveyed in the network are elements I in GF(2)={0,1} and bitwise XOR in GF(2) is utilized as an operation.

II.RELATED WORK

Obligation cycle facilitates in decrease of power utilization in a dense WSN [10][11][15]. Furthermore, mesh cipher method has been drawn its vigilance for improvement of throughput, bandwidth and power effectiveness in asset constraint wireless networks. There have been investigations on the mesh lifetime in WSNs and drawn from upper bounds on mesh lifetime for a non-duty cycle founded WSN. The mesh lifetime top bounds in a cluster founded WSN has been estimated. There are also various works in the publications on broadcasting, connectivity and coverage in obligation cycle founded WSNs. An obligation cycle founded broadcasting scheme with reliability has been proposed. A random duty cycle founded WSN has been advised for dynamic coverage by Hsin et al [20]. Furthermore, Lai et al [10] have furthermore suggested an effective broadcasting design in duty cycled WSNs.

The coverage and connectivity of low duty biked WSN has been studied by Kim et. Al[17]. The data theoretic facet of network coding was presented by Ahlswede et. al[7] for data systems. A random linear mesh cipher based design that presents packet-level capability for both lone unicast and lone multicast connections have been proposed by Rout et al[24]. The aim of the work is to approximate the upper bounds of mesh lifetime in WSN, contemplating (i) random duty cycle, (ii) network encoding, and (iii) combinations of the duty cycle and network encoding. A mesh cipher founded connection paradigm has been proposed. Comprehensive theoretical investigation, replication and presentation investigation have been finished to show the efficacy of the suggested approach.

III.UPPER COMPELLED OF MESH LIFETIME UTILIZING DUTY CYCLE AND NETWORK ENCODING

A. Scheme Mode

A system is considered with N sensor nodes dispersed uniformly in locality A. The locality A with a bottleneck zone B with radius D is shown in Fig. 1. All the N sensor nodes are duty cycle endowed (i.e. swapping between active and dormant states). The nodes are entitled founded on their roles in the mesh as shown in Fig. 1. In the zone B, the nodes are differentiated into two assemblies, such as, relay sensor and mesh coder sensor nodes. The (active) relay sensor nodes (R) convey facts and figures which are developed out-of-doors as well as interior the bottleneck zone.

The (active) mesh coder sensor nodes (N) encode the raw native data which are approaching from out-of-doors the zone B before transmission. The sensor nodes out-of-doors the zone B are marked as I and L in Fig. 1. The leaf sensor nodes (L) occasionally sense facts and figures and transmit them toward the go under. The intermediate sensor nodes (I) relay the facts and figures in the main heading of the Sink S. In the bottleneck zone, the relay nodes can broadcast with the go under utilizing a multihop connection [11]. Although the network coder nodes use a single jump to communicates with the Sink. The radius, D, should be at smallest identical to the maximum transmission variety of a sensor node, so that the data generated outside the bottleneck zone can be relayed through the zone B.

Number of nodes(N)	103
Area(A)	200*200m2
Bottle neck zone radius(D)	60meters
Path loss exponent(n)	2
α_{11}	0.937µ joule/bit
α_{12}	0.787µjoule/bit
α_{2}	0.0172µjoule/bit
E_{sleep}	30µjoule/sec
E_b	25kjoule

$$E_s = t[p(r_s\, e_s+E_{tx})+(1-p)E_{sleep}] \qquad (3)$$

$$E_r = y[p(r_s\, e_s+E_{txr})+(1-p)E_{sleep}] \qquad (4)$$

B. Power Utilization And Upper Bound Of Power Mesh Lifetime

Total energy consumption in the bottleneck zone are viewed as three components, namely, energy utilization (i) to relay the data morsels which are obtained from outside of the bottleneck zone (E1) (ii) due to feeling operation of the (relay) nodes interior the bottleneck zone (E2) (iii) to relay the facts and figures morsels which are generated interior the bottleneck zone (E3). As shown in Fig. 2 (a), sensor nodes in the bottleneck zone may receive multiple exact replicates of the identical data morsels transmitted from out-of-doors of zone B[11]. So, the redundant morsels which sway the mesh lifetime are transmitted interior the zone B. The total number of facts and figures morsels generated outside the zone B is NpA−B A rst [Note: NpA−B A is the mean number of sensor nodes are in hardworking state and N(1 − p)A−B A mean number of nodes that are in doze state in time t and follow binomial distribution]. The facts and figures morsels generated outside the bottleneck Zone is relayed through N B A number of nodes in the bottleneck zone. The total number of facts and figures morsels which are generated out-of-doors and inside of the bottleneck zone in time t is granted by NpA−B A rst+NpB Arst = Nprst. The total traffic, Nprst, is conveyed through NpB A hardworking relay nodes in the bottleneck zone.

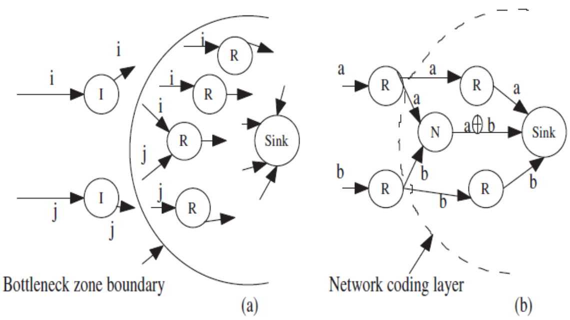

Fig.2. (a) reception of redundant data bits by the boundary relay nodes in the bottle neck zone. (b) XOR network encoding in the network coding layer of bottle neck zone.

Table 1.Parameter Settings

C. Multi Path Based Packet Forwarding

The packet drops, node failures, and errors on wireless links in WSN reduces the reliability of packet delivery in single-path routing schemes [6]. A data packet may travel though multiple paths from source to the Sink in a WSN to enhance the packet reception probability [6][16][17]. In the bottleneck zone analysis, multiple redundant receptions may occur inside the bottleneck zone for the same data bits which are generated outside the zone B. Although sensor nodes are uniformly distributed in the monitored area, practically due to deployment constraints and duty-cycle, each node (outside the boundary of the zone B) may not have the same number of active neighbors inside the bottleneck zone. While transmitting, any node outside of the zone B might have [1,m] number of active neighbors inside the bottleneck zone. Thus, on an average, the number of active neighbors in B who received redundant data is (m+1)/2. The number of forwarding relay nodes need to be reduced (to decrease traffic overhead) based on the required reliability level [25]. The total energy consumption by the nodes in the bottleneck zone to relay the bits that are generated outside the bottleneck zone is,

$$E_{1GD} \geq \sum_{i=1}^{[Np(A-B)/A\ rs,t]} \sum_{j=1}^{[(m+1)/2]} E_{ij} \qquad (5)$$

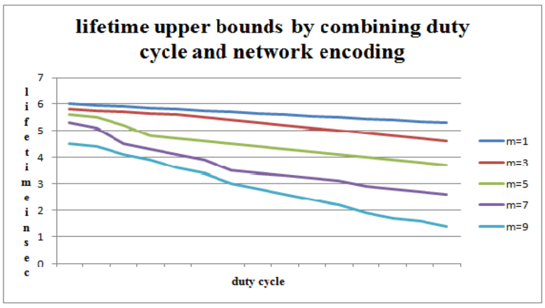

Fig.3. Lifetime of a upper bounds by combining duty cycle and network encoding.

IV.IMPLEMENTATIONS

1) Algorithm 1:Packet process(p_i):

Packet processing at a node inside the network coding layer.

Require: Packet transmission and reception starts, received packets inserted into the RecvQueue().

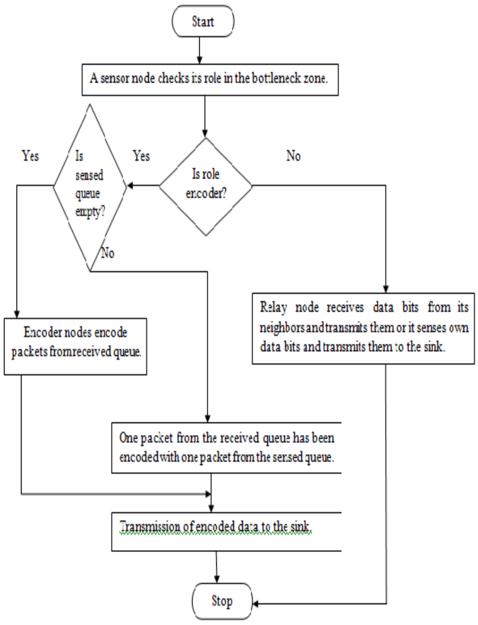

Fig.4. Functionalities of the sensor node in the bottle neck zone.

Ensure: Encoded packet transmitted or discarded.
1. Pick a packet Pi from RecvQueue(Pi)
2. If Packet Pi ∈ ForwardPacketSet(Pi) exit;
3. If Node n ∈ EncoderNodeSet() continue;
4. If native(Pi) then
5. CN =XorEncode();

```
6. Node n transmits the coded packet CN to Sink
7. Insert the processed packet Pi to ForwardPacketSet();
8. else
9 Discard(Pi);
10 endif
10. else
11. Node n acts as relay and transmits the packet Pi to the Sink;
12. endif
13. endif
14. If (RecvQueue() _= empty)
15. goto step 1;
16. else exit;
17. endif
```

2) Algorithm 2: XorEncode():

Encoding algorithm.

Require: A received queue RecvQueue() and a sensed queue SensQueue() is maintained at an encoder node.

Ensure: Generation of network coded packet CN

```
1. If SensQueue() is not empty then continue;
2. Pick a packet Pi from head of the RecvQueue();
3. Pick a packet Pj from head of the SensQueue();
4. CN = Pi ⊕Pj ;
5. else
6. Pick next packet Pi+1 from the RecvQueue();
7. CN = Pi ⊕Pi+1;
10. endif;
11. return CN
```

V.PERFORMANCE EVOLUTION

A. Duty Cycle And Network Encoding

The obligation cycle p of the WSN has been taken from 1% to 10%. As the duty cycle p rises in the mesh the lifetime decreases in the mesh. On the increase of duty cycle propose that there is an increase in the number of active nodes in the mesh. As the duty cycle increases from 1% to 10% the number of transmissions and receptions in the network increases. Therefore, the power utilization of the nodes is also rises in the mesh. It has been observed from the Fig. 5 that the lifetime time with obligation cycle and mesh coding is more than only using duty cycle. There is an boost of 2.5% to 9.5% of mesh lifetime by using the suggested mesh cipher founded communication algorithm for 1% to 10% duty cycle respectively in the obligation biked WSN. The enhancement of lifetime is due to the introduction of mesh cipher nodes beside the go under. Furthermore, in Fig. 6 power consumption (per node) has been shown for a obligation cycle based WSN with mesh coding and without mesh coding. The per node power consumption in case of a WSN with obligation cycle is more than a WSN with obligation cycle and mesh coding.

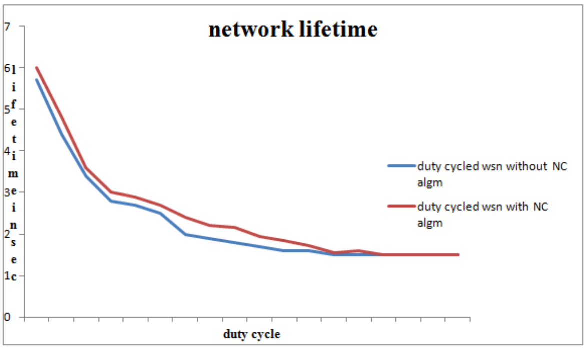

Fig. 5. Network lifetime analysis.

The package consignment ratio (PDR) and the package latency (PL) have been assessed by circulating 100 sensor nodes consistently with varying the locality of the deployment region. The node density (i.e. nodes per unit locality) is varied by repairing the duty cycle. The PDR has been shown for three situations, namely, (i) 1/3 (34% approx.) of the total obtained packet loss at go under with the suggested mesh cipher founded approach, (ii)1/6(17%approx.) package loss, without mesh cipher approach and (iii) 1/3 (34% approx.) package loss, without mesh cipher approach.

When the density is reduced, the number of hardworking nodes per unit area is less. Therefore, less amount of traffic is effectively forwarded to the Sink. In the suggested approach and in the multi-path forwarding without mesh cipher, the PDR is reduced for reduced node densities. Although, as the node density increases, the suggested mesh cipher approach has considerably more PDR than the customary multi-path forwarding. With the proposed approach, up-to 25% PDR improvement can be achieved at the Sink by decoding the encoded data packets in case of loss of a fraction of conveyed packets due to connection failure.

B. Energy Consumption

The energy consumption such as E_G, E_D, E_{NC} and E_{NCD} conform the following inequalities,

$$ENCD \leq ENC \leq EG, ENCD \leq ED \leq EG$$
$$\Rightarrow TuNCD \geq TuNC \geq TG,\ TuNCD \geq TuD \geq TG$$

where, EG and TG are the total energy consumption and lifetime in a non-duty cycle based WSN respectively. As the energy consumption increases in a WSN, the network lifetime decreases. It can be also observed from the simulation results that TuNCD ≥ TuD and the slope of the suggests that on further increase of duty cycle from (0.1 to 1], the network lifetime decreases. Therefore, in case of a nonduty cycle based network [5], the WSN lifetime TG is very low in comparison to the proposed approaches.

C. Effect Of Mac And Routing Protocols On Network LIfetime

In randomized duty cycle based WSN, each sensor node randomly generates a working schedule. Energy consumption is also dependent on the working schedule of the sensor nodes. Due to lack of co-ordination among the sensor nodes some amount of energy may be wasted due to collision of data at the receiver. Thus, the network lifetime may be affected by nonideal MAC (medium access control) protocols. Furthermore, at the physical layer, the realistic conditions of wireless link can affect the intended network lifetime. The wireless link status can change with time and frequency. Different routing protocols may deal with different forwarding schedule of a node and different paths from the source to destination. An ideal best routing protocol can deliver data to the Sink with $[(M+1)/2]=1$ which is difficult design and it needs significant amount of control packet dissemination in a WSN. In the worst case scenario $[(m+1)/2^{(\omega+1)/2}]$ number of redundant data packets will be transmitted in a WSN from a source to destination. Here, the ω is the maximum number of hops from the boundary of a deployed region to the bottleneck zone (where, the data bits generated outside the bottleneck zone follows a uniform distribution in the range of values $[1,\omega]$ for multihop communication to reach the bottleneck zone). It has been observed from the simulations that with flood routing the simulated network lifetime upper bounds are less than the proposed analytical lifetime upper bounds. Therefore, the routing protocols affect the intended network lifetime.

ACKNOWLEDGMENT

I would like to thank P.S.Tamizharasan for helpful discussions about this work.

VII.CONCLUSION

In a wireless sensor network (WSN), the area round the Sink types a bottleneck zone where the traffic flow is greatest. Thus, the lifetime of the WSN mesh is determined by the lifetime of the bottleneck zone. The lifetime top bounds have been estimated with (i) obligation cycle, (ii) network cipher and (iii) blends of obligation cycle and network cipher. It has been discerned that there is a reduction in power consumption in the bottleneck zone with the proposed approach. This in turn will lead to boost in network lifetime. Replication outcomes reveal that there is an increase of 2.5% to 9.5% of mesh lifetime by utilizing the proposed mesh coding based algorithm for 1% to 10% obligation cycle respectively in a obligation cycled WSN. It has been shown that the per node energy utilization in case of a WSN with obligation cycle is more than a WSN with obligation cycle and mesh coding. The go under obtains roughly 50% more data with identical energy utilization in the bottleneck zone. More capacity of facts and figures leads to more accuracy of conclusion making at the Sink. The package consignment ratio and package latency for the suggested approach have furthermore been investigated with packet deficiency at the Sink. A important enhancement in packet delivery ratio has been accomplished with the proposed mesh cipher approach. Whereas, packet latency is high for reduced node density but with increase of node density the proposed approach has considerably low latency than forwarding without mesh cipher in a duty biked WSN.

REFERENCES

[1]. H. R. Karkvandi, E. Pecht, and O. Y. Pecht, "*Effective lifetime-aware routing in wireless sensor networks*," IEEE Sensors J., vol. 11, no. 12, pp. 3359–3367, 2011.

[2]. X. Y. Wang, R. K. Dokania, and A. Apsel, "*PCO-based synchronization for cognitive duty-cycled impulse radio sensor networks*," *IEEE Sensors J.*, vol. 11, no. 3, pp. 555–563, 2011

[3]. S. Lee and S. H. Lee, "*Analysis of network lifetime in cluster-based sensor networks*," *IEEE Commun. Lett.*, vol. 14, no. 10, pp. 900–902, 2010.

[4]. R. R. Rout, S. K. Ghosh, and S. Chakrabarti, "*A network coding based probabilistic routing scheme for wireless sensor network*," in *Proc. 2010 Int. Conf. on Wireless Communication and Sensor Networks*, pp. 27–32.

[5]. Q. Wang and T. Zhang, "*Bottleneck zone analysis in energy-constrained wireless sensor networks*," *IEEE Commun. Lett.*, vol. 13, no. 6, pp. 423– 425, June 2009.

[6]. P. K. K. Loh, H. W. Jing, and Y. Pan, "*Performance evaluation of efficient and reliable routing protocols for fixed-power sensor networks*," *IEEE Trans. Wireless Commun.*, vol. 8, no. 5, pp. 2328–2335, 2009.

[7]. O. M. Al-Kofahi and A. E. Kamal, "*Network coding-based protection of many-to-one wireless flows*," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 5, pp. 797–813, 2009.

[8]. Z. Cheng, M. Perillo, and W. B. Heinzelman, "*General network lifetime and cost models for evaluating sensor network deployment*," *IEEE Trans. Mob. Comput.*, vol. 7, no. 4, pp. 484–497, 2008.

[9]. D. Lun, M. Medard, R. Koetter, and M. Effros, "*On coding for reliable communication over packet networks*," *Physical Commun.*, vol. 1, pp. 3–20, 2008.

[10]. C. F. Hsin and M. Liu, "*Randomly duty-cycled wireless sensor networks: dynamic of coverage*," *IEEE Trans. Wireless Commun.*, vol. 5, no. 11, pp. 3182–3192, 2006.

[11]. S. Katti, H. Rahul, W. Hu, D. Katabi, M. Medard, and J. Crowcroft, "*XORs in the air: practical wireless network coding*," *IEEE Trans. Networking*, vol. 16, pp. 497–510, 2008.

[12]. L. Keller, E. Atsan, K. Argyraki, and C. Fragouli, "*Sensecode: network coding for reliable sensor networks*," EPFL Technical Report, 2009.

[13]. I. H. Hou, Y. E. Tsai, T. F. Abdelzaher, and I. Gupta, "*Adapcode: adaptive network coding for code updates in wireless sensor networks*," in *Proc. 2008 IEEE INFOCOM*, pp. 2189–2197.

[14]. R. R. Rout, S. K. Ghosh, and S. Chakrabarti, "*Network coding-aware data aggregation for a distributed wireless sensor network*," in *Proc.2009 IEEE ICIIS*, pp. 32–36.

[15]. A. R. Lehman, "*Network coding*," Ph.D. dissertation, Massachusetts Institute of Technology, USA, Feb. 2005.

[16]. E. Felemban, C. G. Lee, and E. Ekici, "*Mmspeed: multipath multispeed protocol for QoS guarantee of reliability and timeliness in wireless sensor networks*," *IEEE Trans. Mob. Comput.*, vol. 5, no. 6, pp. 738–754, 2006.

[17]. D. Kim, C. F. Hsin, and M. Liu, "*Asymptotic connectivity of low dutycycled wireless sensor networks*," in *Proc. 2005 IEEE MILCOM*, pp. 2441–2447.

[18]. D. Lun, M. Medard, R. Koetter, and M. Effros, "*On coding for reliable communication over packet networks*," *Physical Commun.*, vol. 1, pp. 3–20, 2008.

[19]. R. R. Rout, S. K. Ghosh, and S. Chakrabarti, "*A network coding based probabilistic routing scheme for wireless sensor network*," in *Proc. 2010 Int. Conf. on Wireless Communication and Sensor Networks*, pp. 27–32.

[20]. S. Yang and J. Wu, "*Efficient broadcasting using network coding and directional antennas in MANETs*," *IEEE Trans. Parallel Distrib. Syst.*, vol. 21, no. 2, pp. 148–161, 2010.

[21]. S. Katti, H. Rahul, W. Hu, D. Katabi, M. Medard, and J. Crowcroft, "*XORs in the air: practical wireless network coding*," *IEEE Trans. Networking*, vol. 16, pp. 497–510, 2008.

[22]. L. Keller, E. Atsan, K. Argyraki, and C. Fragouli, "*Sensecode: network coding for reliable sensor networks*," EPFL Technical Report, 2009.

[23]. I. H. Hou, Y. E. Tsai, T. F. Abdelzaher, and I. Gupta, "*Adapcode: adaptive network coding for code updates in wireless sensor networks*," in *Proc. 2008 IEEE INFOCOM*, pp. 2189–2197.

[24]. R. R. Rout, S. K. Ghosh, and S. Chakrabarti, "*Network coding-aware data aggregation for a distributed wireless sensor network*," in *Proc. 2009 IEEE ICIIS*, pp. 32–36.

[25]. A. R. Lehman, "*Network coding*," Ph.D. dissertation, Massachusetts Institute of Technology, USA, Feb. 2005.