MSR: A Multipath Secure Reliable Routing Protocol for W S N

Presented by:

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Mariam Ahmed Moustafa

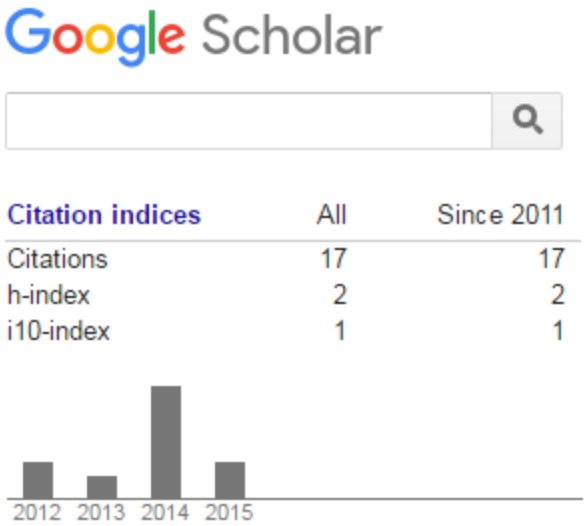
- Is a talented Researcher, Teaching Assistant, Co-Founder of Dimensions Egypt. She received a Master of Science degree in **Computer Science and Systems Engineering**, Faculty of Engineering, Alexandria University, Egypt. She started her career as a Java software developer at ISFP (Integrated Solutions for Ports) for six years and IT Analyst at Unilever, then she joined the university as a teaching assistant for 6 semesters, after then she became the BlackBerry Developer Community Manager by developing dozens of top rated/paid mobile applications and games. In 2014, she establishes her own-business as a software company called "Dimensions", which is specialized in developing 2D/3D and video games, mobile applications and Interactive architecture modeling. Mariam now is looking for applying to the next logical step in her life goals to be a PhD student.

- Mariam dream to make a big change in her society by typically model the Arab-African tech-women. She loves drawing. She can be contacted at: elansary.mam@gmail.com

MSR Publications

- [2] Mariam Moustafa, Moustafa Youssef and Nazih Elderini, "**MSR: A Multipath Secure Reliable Routing Protocol for WSNs**", The 9th ACS/IEEE International Conference on Computer Systems and Applications, AICCSA 2011, Sharm El-Skeikh, Egypt, December **2011**.

- [3] Mariam Moustafa, Moustafa Youssef. Nazih Elderini and Magdy Abd-Elazim Ahmed "**Analysis of MSR Routing Protocol for WSNs**", The 12th IEEE International Conference on Wireless Information Technology and Systems ICWITS **2012**, Hawaii, USA, November **2012**.



Objectives

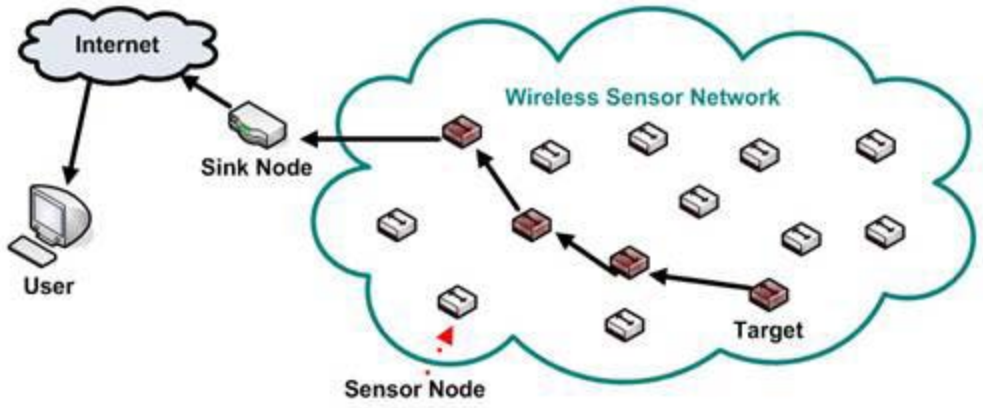
1. Establish the need for secure routing in WSNs.
2. Present the main contributions of MSR scheme.
3. Analyze the proposed scheme and discuss the experimental results.
4. Suggesting future extensions.

Agenda

- Introduction.
- Motivation.
- MSR: A **M**ultipath **S**ecure **R**eliable Routing Protocol for WSNs.
- Scheme analysis.
- Experimental Results.
- Conclusion.
- References.

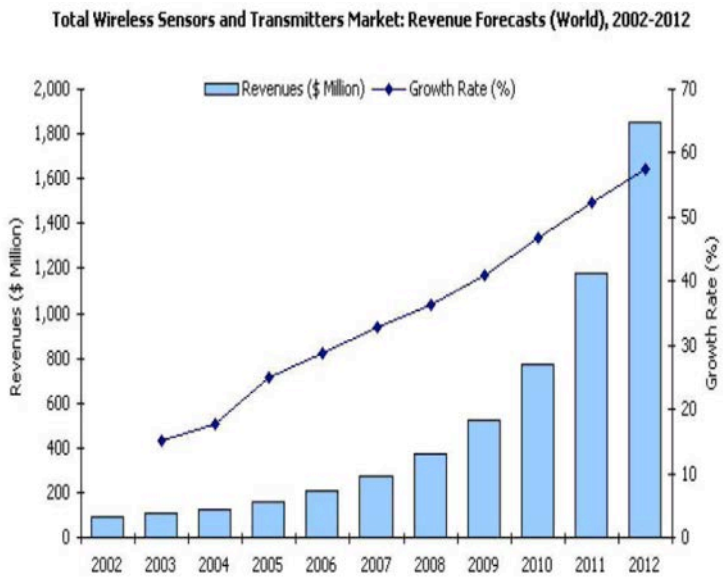
Introduction: WSNs Definition

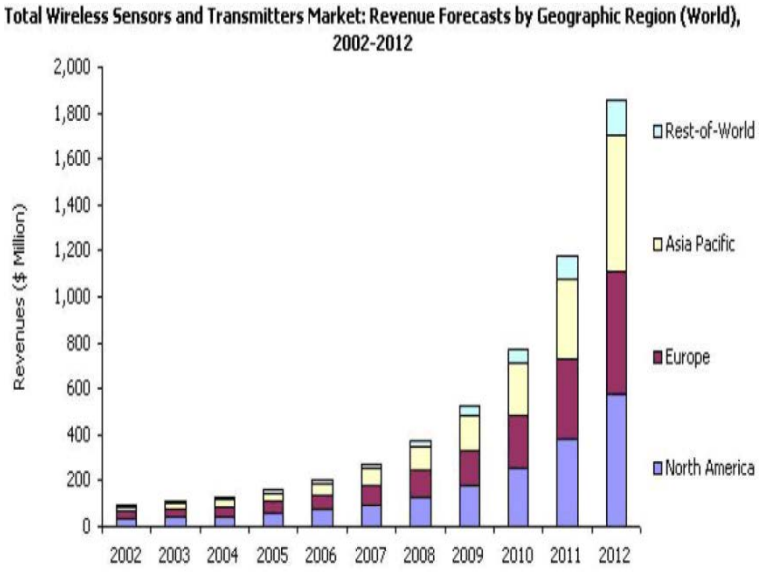
- Recent advances in wireless communications have motivated the widespread of wireless sensor networks (WSNs), with the development of extremely small, low-cost, and low-power of multi functional sensor nodes.



Introduction: WSNs Market Trend

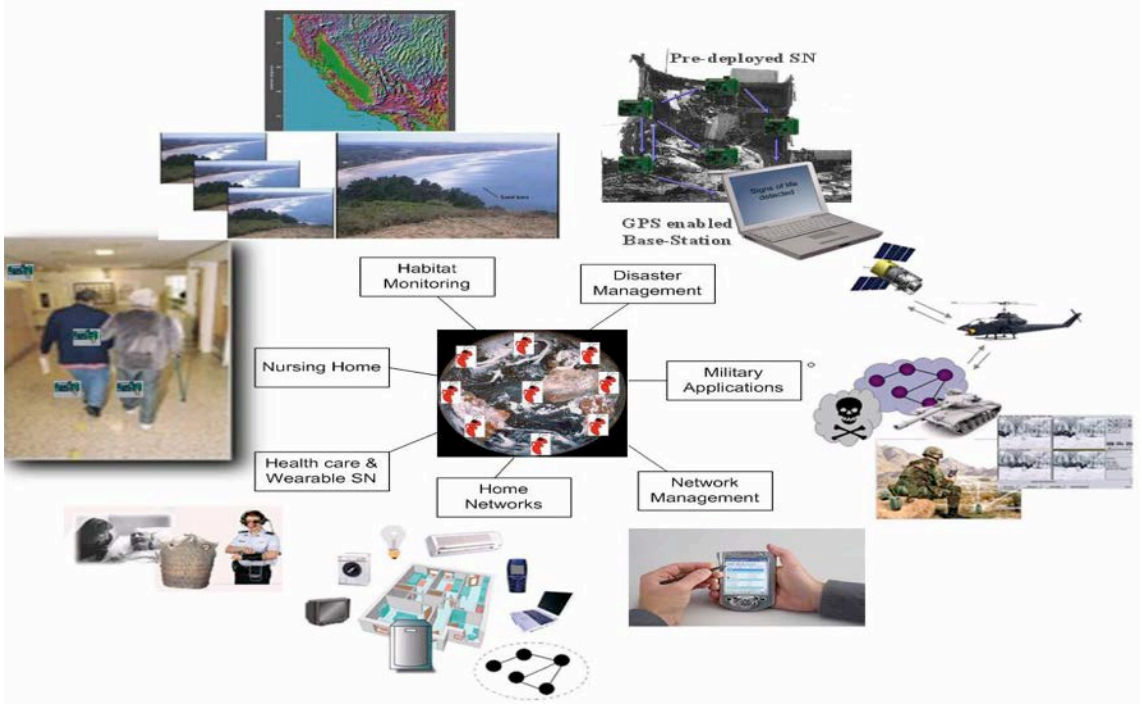
- WSNs market is growing worldwide. There is a drastic change in last few years and these number increases in future.





Introduction: WSNs Applications

- WSNs have attracted huge interest from the wireless research community due to their potential applications for both the military and civilian domains.



Introduction: WSNs Limitations

- Power restrictions.
- Storage restrictions.
- Limited computational power
- Lack of global IDs.
- Random deployment.
- Cooperative concept.
- The hostile and remote environment.

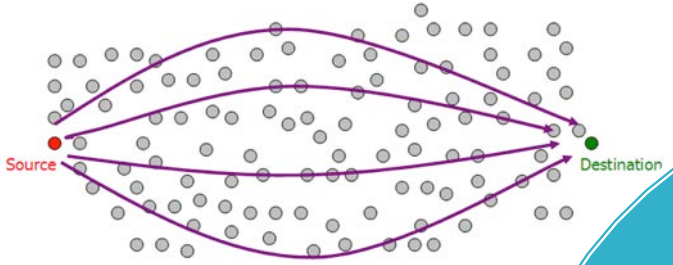
Motivation – Why Secure Routing?

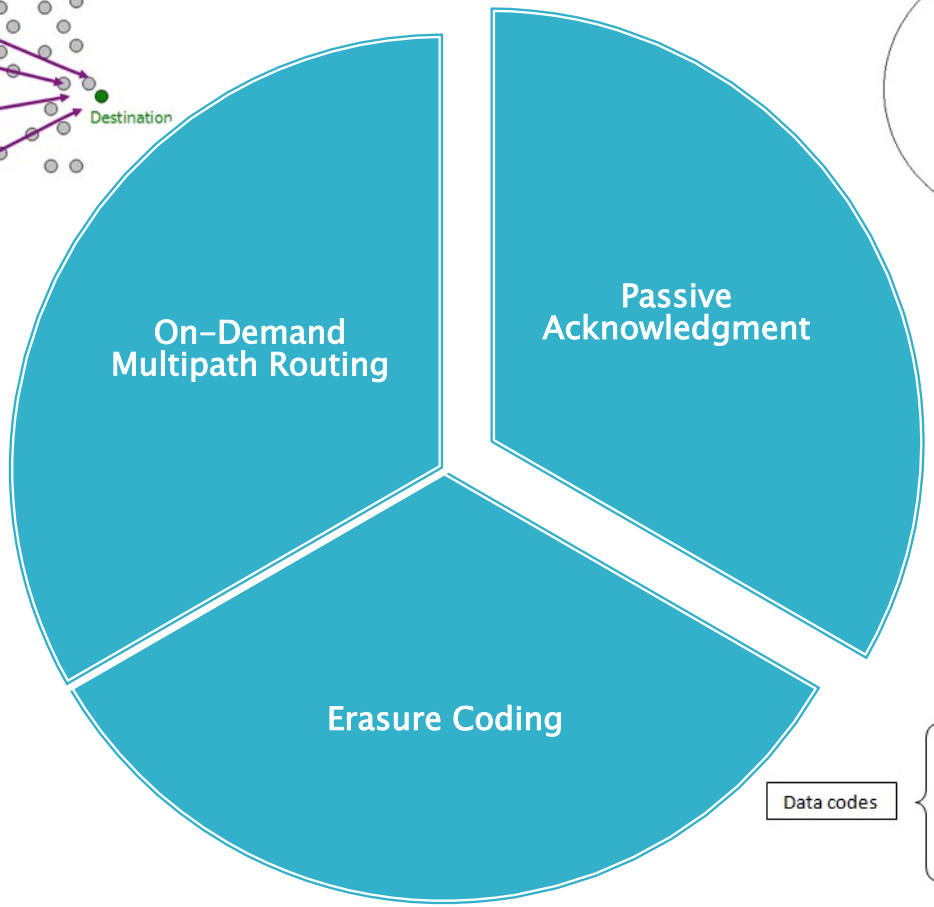
- Communication **security** and reliability are two **important issues** in WSNs.
- WSNs possess a number of **additional security attacks**.
- **Infeasible** of using **traditional security solutions** like, cryptography which requires complex processing to provide encryption to the transmitted data.
- **Lack of secure routing protocols**, many sensor network routing protocols have been proposed for WSNs, only few of them addressed secure routing.
- Lightweight secure routing protocols should be addressed.

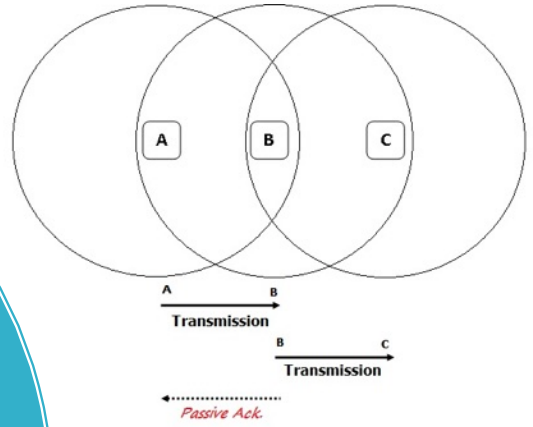
Contribution

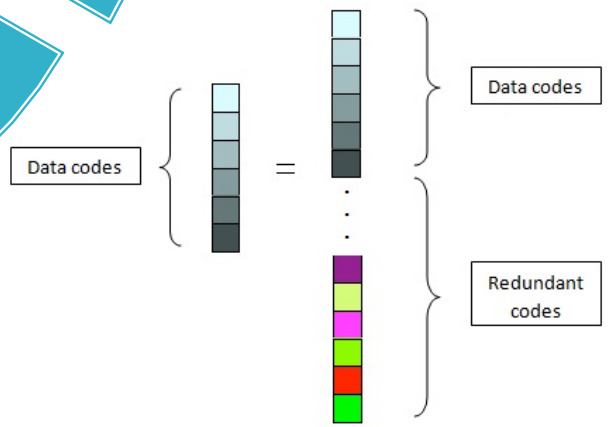
- Proposing a novel MSR secure routing protocol.
- Utilizing erasure coding as a splitting method.
- Utilizing passive acknowledgment as a security validation method.
- Providing security study against major attacks.
- Evaluating MSR scheme‘s performance.

MSR: A Multipath Secure Reliable Routing Protocol for WSNs



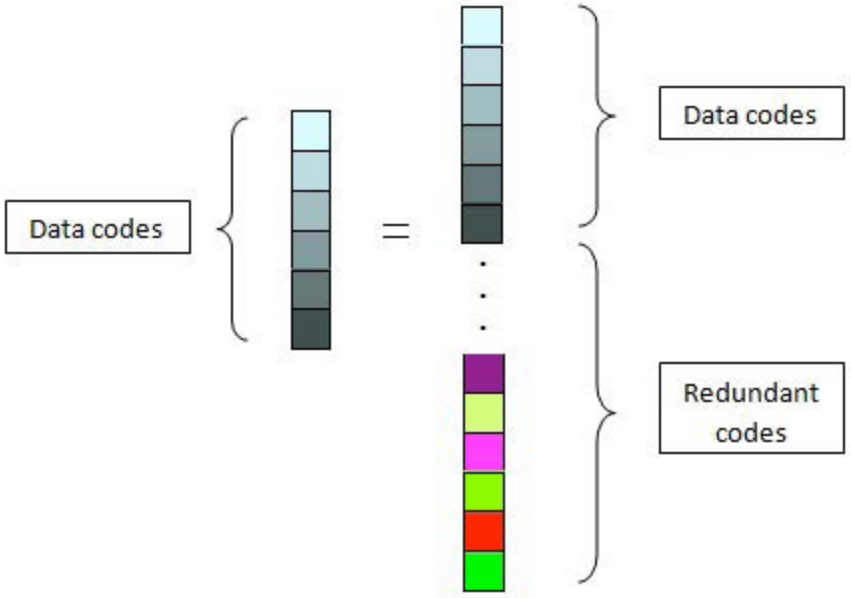






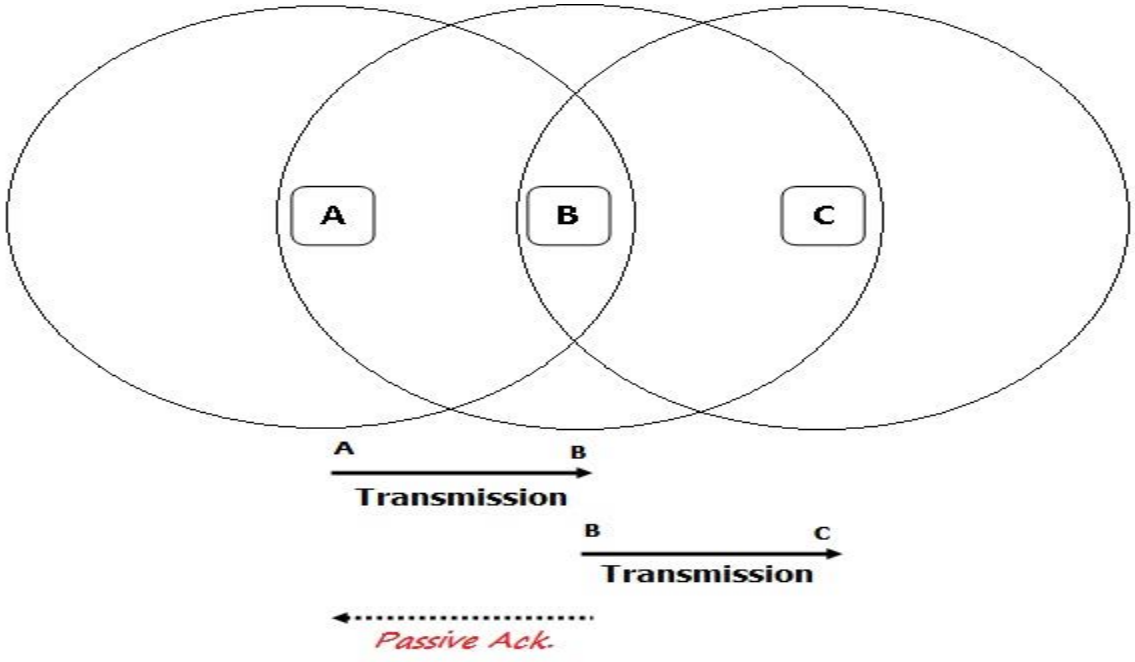
Background – Erasure Coding

- Erasure coding is a forward error correction (FEC) code for the binary erasure channel, which transforms a message of m blocks into a longer message with n blocks (codeword) such that the original message can be reconstructed from a subset of the n symbols. The fraction r=m/n is called the code rate.



Background – Passive Acknowlegdement

- Passive Acknowledgment (PACK) refers to the sender passively listens after finishing the message transmission to confirm that the message has been received by the destination (indirect overhearing) .



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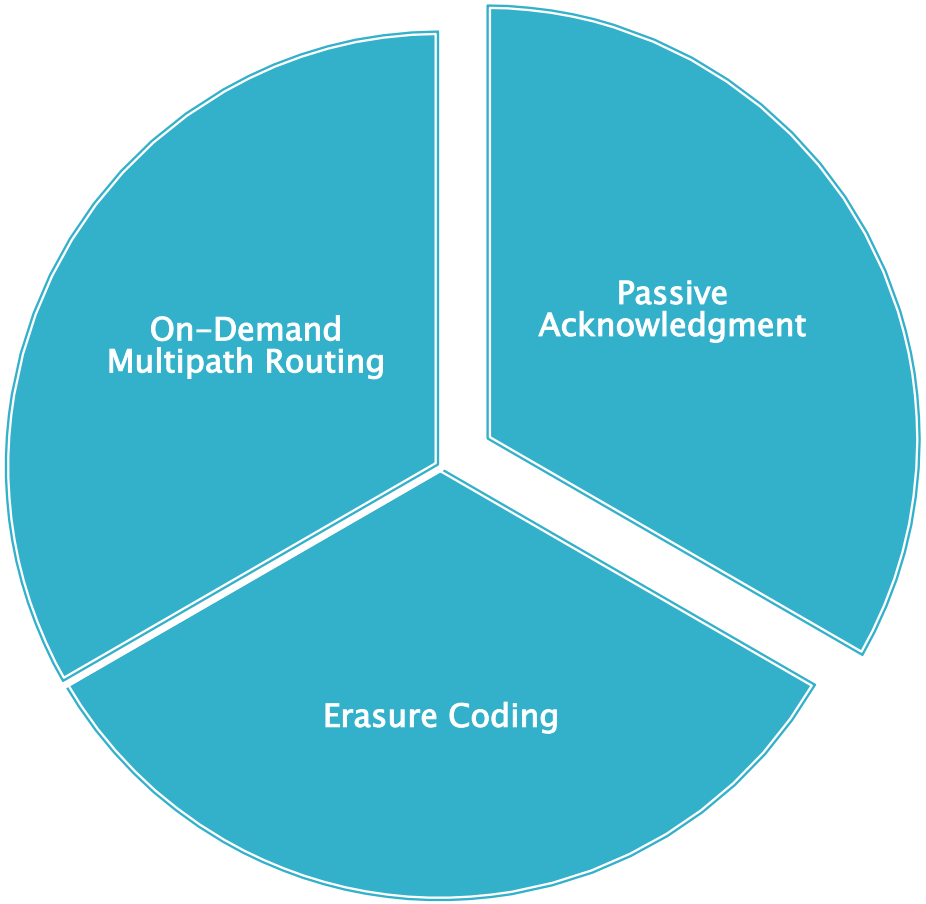
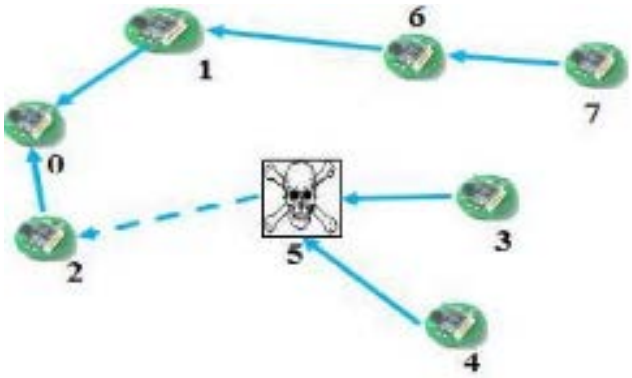


Security Analysis

- Security Attacks in WSNs:
  - Blackhole attack.
  - Selective forwarding attack.
  - Hello flood attack.
  - Acknowledgment spoofing attack.
  - Replay attack.
  - Alter attack.
  - Spoofing attack.
  - Sinkhole attack.
  - Wormhole attack.
  - Sybil attack.

Security Analysis (cont.)

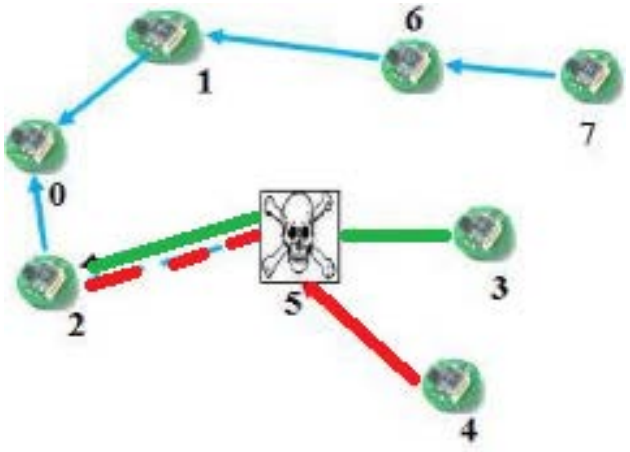
- **Security Attacks Definitions in WSNs:**
  - **Blackhole attack**: when a malicious node drops all the packets through it.



Security Analysis (cont.)

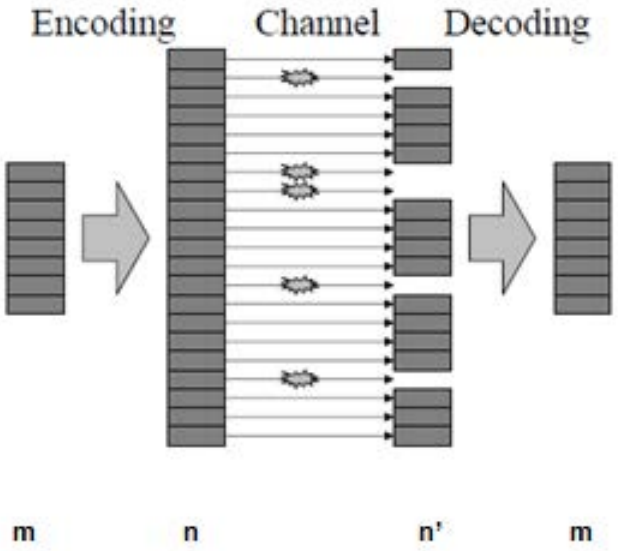
- Security Attacks Definitions in WSNs:

- Selective forward attack: when a malicious node can however drop or forward certain messages (it selectively forward the packets).



Splitting Method using Erasure Coding

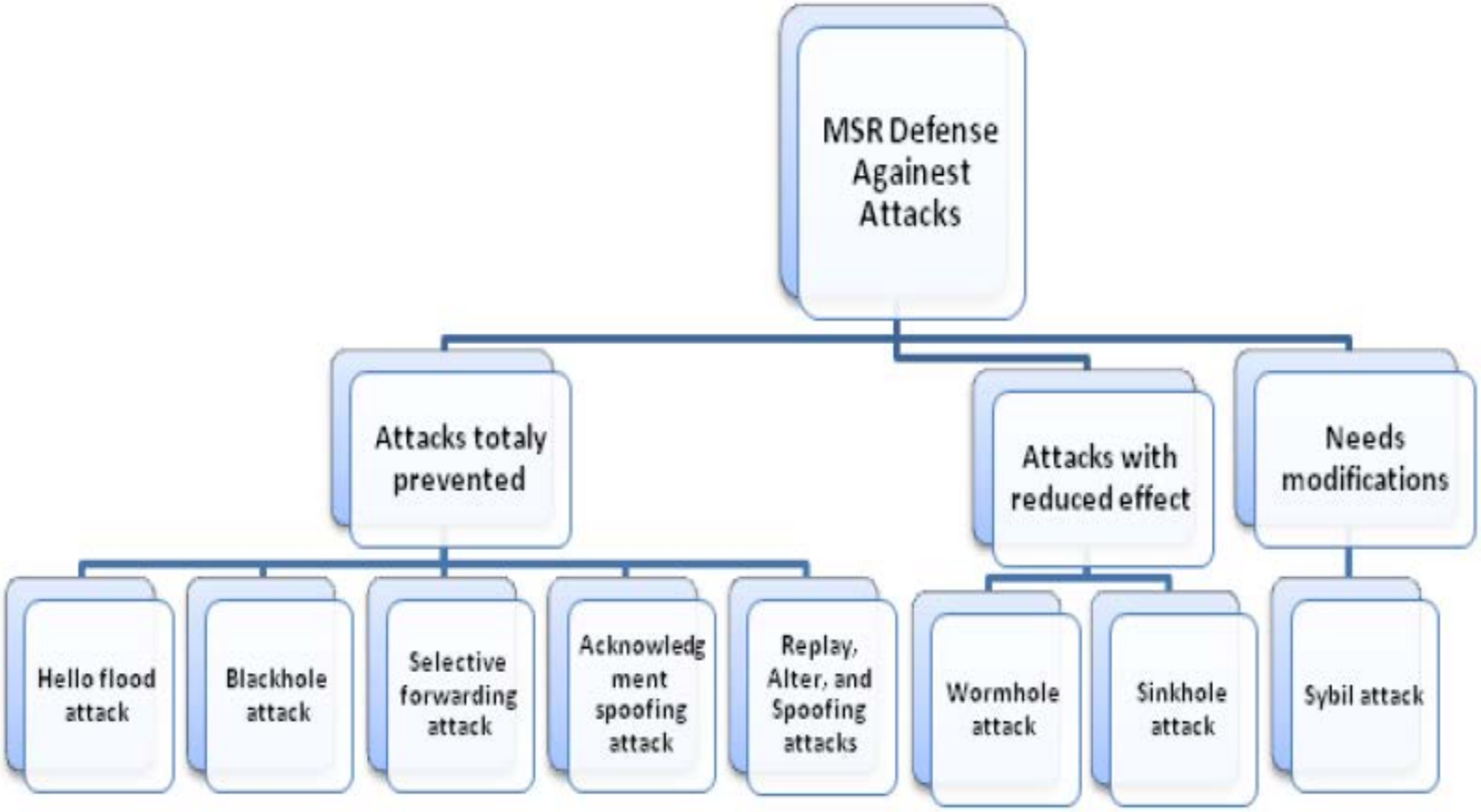
- Erasure coding provides an efficient option for achieving reliability against the noisy channel and efficient data replication without end-to-end retransmission.



Security Checks via Enhanced Passive Acknowledgment

- A consistent dropping of a packet from a neighbor can be used as a sign of a blackhole attack.
- A partial dropping of a packet from a neighbor can be used as a sign of a selective forward attack.
- Packet headers can be checked to detect any malicious changes in the headers. This can be used to detect spoofing.
- The packet content itself can be analyzed to detect any unauthorized changes to the packet. This can be used to detect alter.

Security Analysis (cont.)



Experimental Results

- MSR protocol is implemented using NS-2 simulator. The main objective of the simulation is to evaluate the effectiveness of MSR relative to AOMDV (Ad hoc On-demand Multipath Distance Vector) which guarantees link-disjoint paths, doesn't use alternative paths simultaneously, uses retransmission concept for reliability and no security support.

- Performance Metrics:
  - Packet Delivery Ratio
  - End-to-End Delay
  - Normalized Routing Overhead
  - Resistance against Attacks

Experimental Results (cont.)

- Simulation parameters

  Sensor nodes are spread randomly over a at square area of dimensions 1000 * 1000 m2. All experiments are performed against different network sizes (W) ranging from 50 to 200 sensor nodes.

Table 6.1: *Simulation Parameters*

Parameters	Value
Simulation Time	1000 sec
Number of nodes	50, 100, 150 and 200
Network topology	1000*1000 m^2 square region
Traffic Source	CBR
Packet Size	1024 byte
Network Deployment	Random deployment
MAC Layer	MAC 802.11
Propagation Model	Two-Ray-Ground model
Mobility Model	Static
Seed	1, 3, and 7

Experimental Results (cont.)

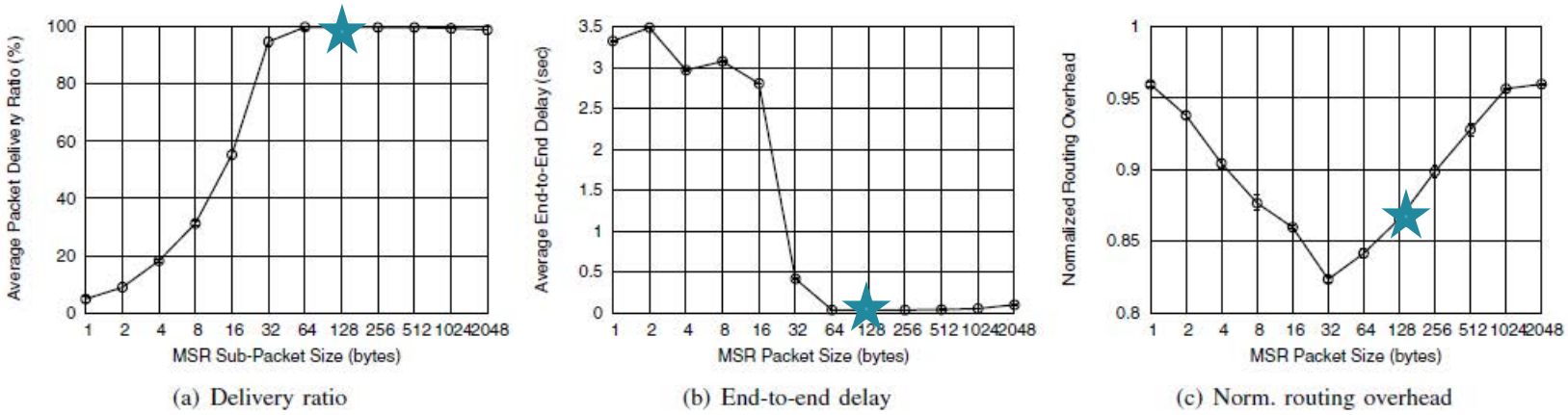
- Simulation Setup
  - First Setup Experiment (effective sub-packet size)
  - Second Setup Experiment (effective coding rate)

Experimental Results (cont.)

- **Important parameters:**
  - **Packet size**: This parameter represents the size of the packets transmitted over the network.
  - **Code rate**: This parameter represents the ratio of the total number of packets generated by the erasure coding technique to the sufficient number of packets to reconstruct the original message (n/m).

Experimental Results (cont.)

- First Setup Experiment (effective sub-packet size)

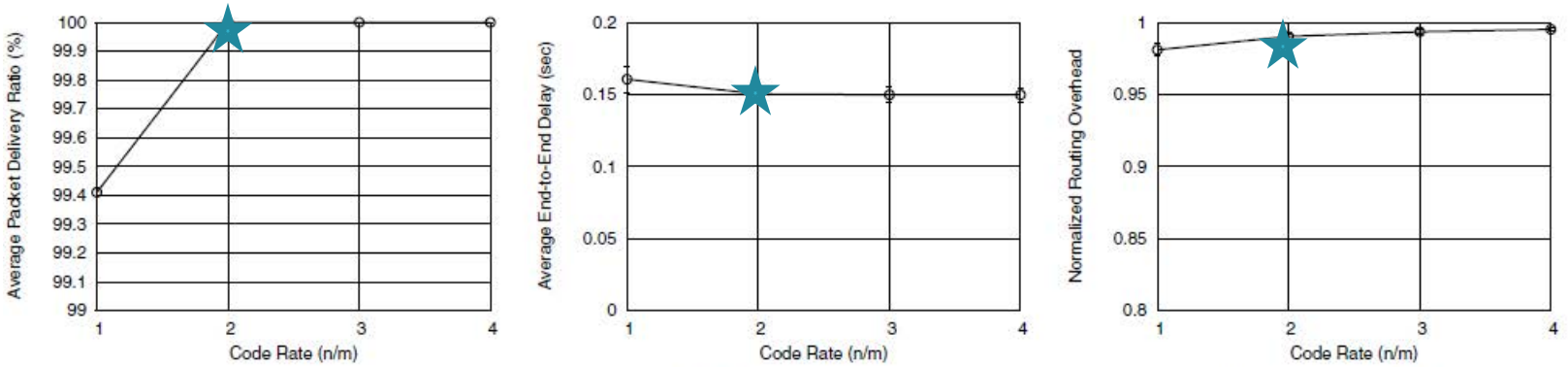


(a) Delivery ratio (b) End-to-end delay (c) Norm. routing overhead

Fig. 2. Effect of changing the sub-packet size on the performance of MSR.

Experimental Results (cont.)

- Second Setup Experiment (effective coding rate)

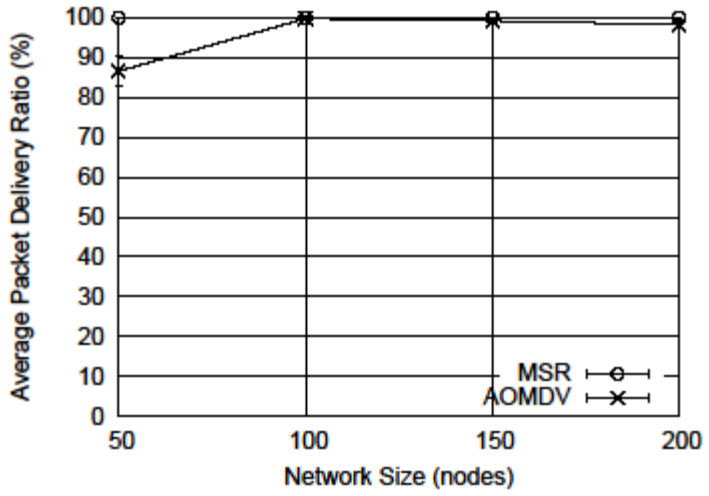


(a) Delivery ratio (b) End-to-end delay (c) Norm. routing overhead

Fig. 3. Effect of changing the coding ratio on the performance of MSR.

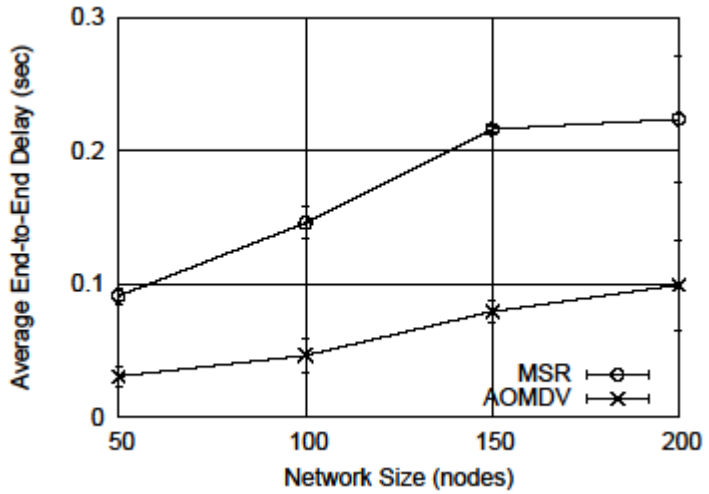
Experimental Results (cont.)

- MSR vs. AOMDV
  - Data Packet Delivery Ratio
    - The results show that MSR outperforms AOMDV especially for small network sizes.



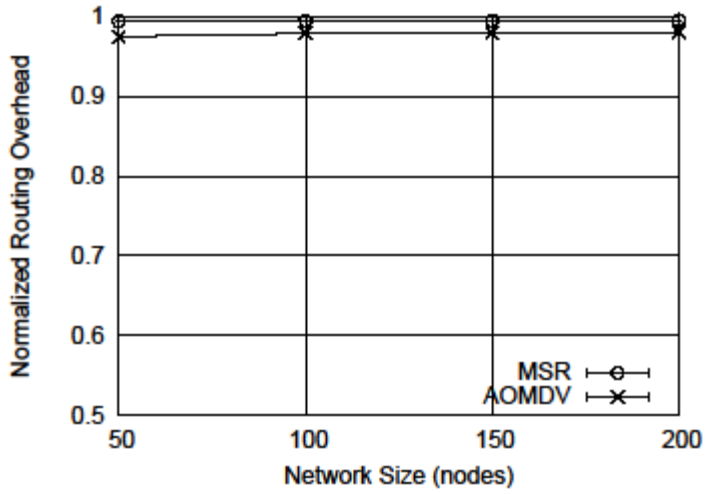
Experimental Results (cont.)

- MSR vs. AOMDV
  - End-to-End Delay
    - End-to-end delay is increased in MSR compared to AOMDV as MSR needs extra time to encode, send, decode and reconstruct the original message.



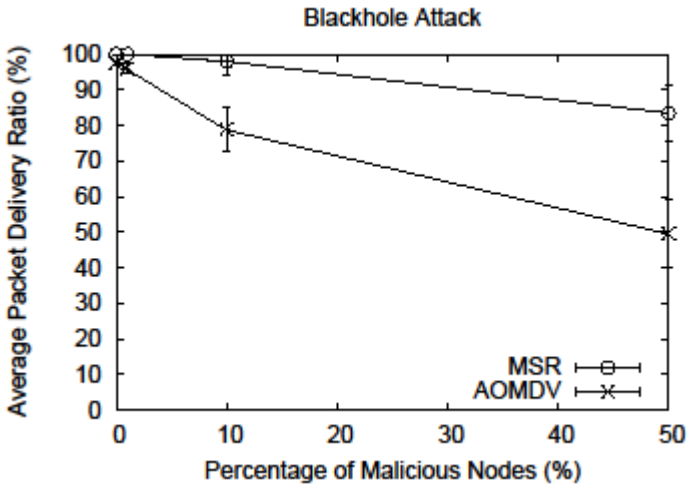
Experimental Results (cont.)

- MSR vs. AOMDV
  - Routing Overhead
    - The results show that MSR has a slightly higher overhead compared to AOMDV.



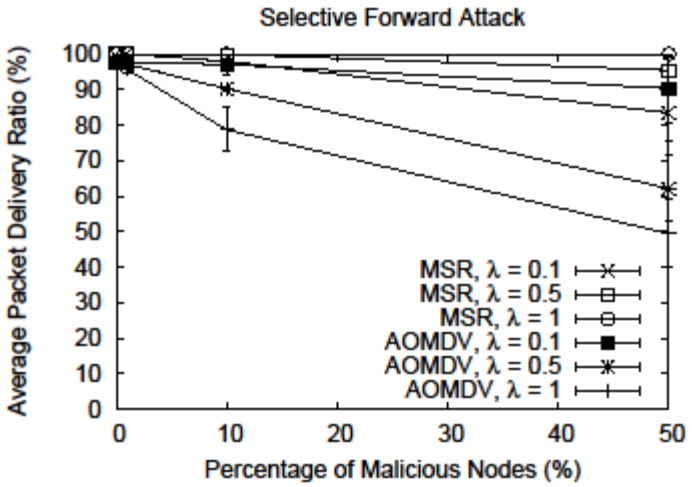
Experimental Results (cont.)

- Resistance against Attacks
  - Against blackhole attack
    - MSR can achieve significant gain, more than 40%, as compared to AOMDV in the exist of blackhole attack.



Experimental Results (cont.)

- Resistance against Attacks
  - Against grayhole (selective forward) attack
    - the selective forwarding attack is less severe than the blackhole attack as expected. As noticed the packet's delivery ratio improves while the dropping probability decreases in both protocols



Analytical Analysis

- Analytical Measures:
  - P_{o_s} → The successful delivery probability of a transmitted message.
  - $P_{o_{\hat{q}}}$ → The successful delivery probability of a transmitted message if a malicious node can forward or drop a packet with probability.
  - M_{max} → The maximum number of attackers that MSR is resistant to (= N – m) .

Analytical Analysis (cont.)

- Analytical Parameters

Table 5.1: *Analytical Analysis Notation*

Symbol	Explanation
N	Total number of disjoint routes.
M	Number of malicious routes due to nodes physical failure or certain attack.
n	Total number of erasure-coded packets.
m	Sufficient number of packets to reconstruct the original message.
γ	Probability of a node to be malicious.
δ	Number of hops or nodes per route.
P_o	The successful delivery probability of a transmitted message.
$P_{o_{\hat{q}}}$	The successful delivery probability of a transmitted message if a malicious node can forward or drop a packet with probability.
M_{max}	The maximum number of attackers that MSR is resistant to.

Analytical Analysis (cont.)

- We can model the transmission of a packet on a route as a Bernoulli trials with successful probability (1 – q) and unsuccessful probability q.

$$q = 1 - [(1-\gamma)^{\delta}] \tag{5.1}$$

- The successful delivery probability of sending block of packets per route P_{o_s}.

$$P_{o_s} = P_r(N - M \geq \frac{m}{s}) \tag{5.4}$$

$$= \begin{cases} \sum_{i=\frac{m}{s}}^{N} \binom{N}{i}(1-q)^i q^{N-i} & ,N \geq \frac{m}{s}; \\ \\ 0 & ,\text{otherwise.} \end{cases} \tag{5.5}$$

Analytical Analysis (cont.)

- The probability $\hat{q}$ is that a malicious route has at least a malicious node and will not forward a packet with probability $\hat{q}$, then can be calculated as in Equation (5.6).

$$\hat{q} = 1 - [(1 - (\gamma\lambda))^{\delta}] \tag{5.6}$$

- Therefore $P_{o_{\hat{q}}}$ can be calculated by replacing each unsuccessful probability q with $\hat{q}$.

$$P_{o_{\hat{q}}} = P_r(m \leq N - M) = P_r(N - M \geq m) \tag{5.7}$$

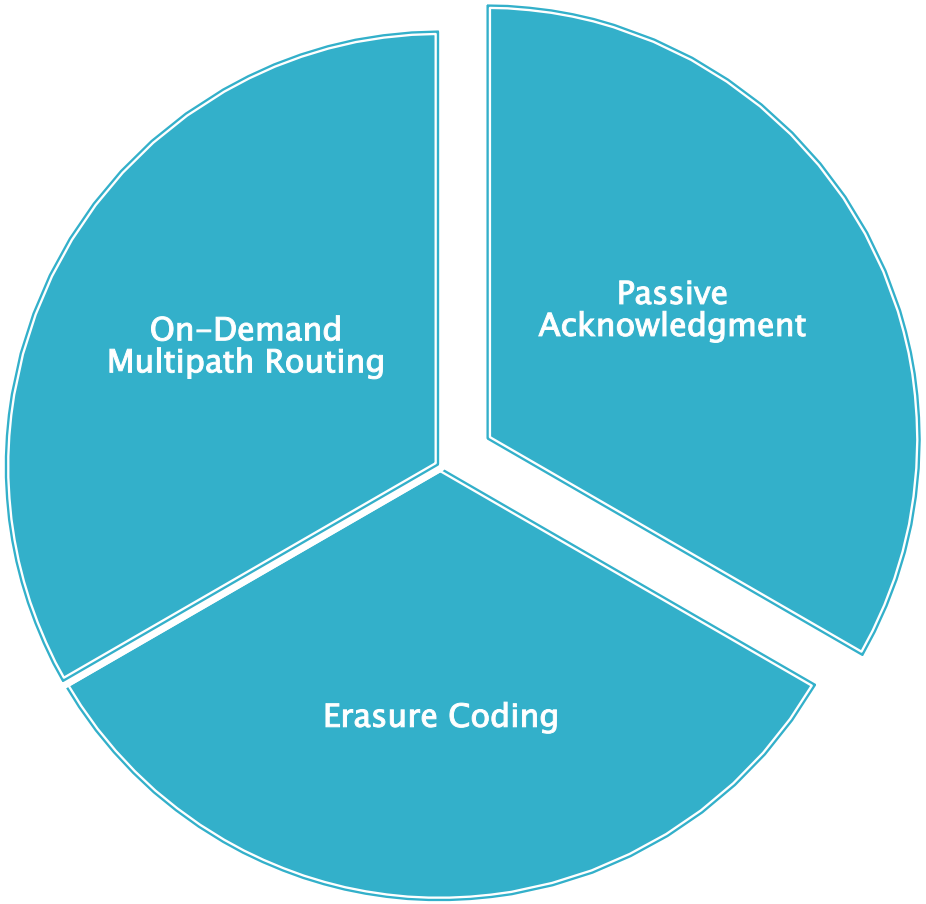
$$= \begin{cases} \sum_{i=m}^{N} \binom{N}{i} (1-\hat{q})^i \hat{q}^{N-i} & ,N \geq m; \\ 0 & ,\text{otherwise.} \end{cases} \tag{5.8}$$

MSR Complexity

- MSR route discovery algorithm is **O(bd)** where,
  - b : number of a node's neighbors
  - d : the max number of hops
- Erasure coding can be performed in a **linear time** as shown in [10, 11 and 12] then it adds O(n).
  - n : the number of spitted shares.
- The security checks of PACK are performed simultaneously with the running of discovery with a **constant** magnitude, so the order still O(K.bd) where, K : is constant.

- The total complexity of MSR is O(K.bd) + O(n) .

Conclusion


On-Demand
Multipath Routing
Passive
Acknowledgment
Erasure Coding

Thank You

Questions

References

- [1] T.Kavitha and D.Sridharan, “**Security vulnerabilities in wireless sensor networks: A survey**”, Journal of Information Assurance and Security, 2010.

- [2] Mariam Moustafa, Moustafa Youssef and Nazih Elderini, "**MSR: A Multipath Secure Reliable Routing Protocol for WSNs**", The 9th ACS/IEEE International Conference on Computer Systems and Applications, AICCSA 2011, Sharm El-Skeikh, Egypt, December 2011.

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Related Work

- Recent advances in wireless sensor networks have led to many new protocols specially designed for but few of them consider security.
- H-SPREAD[2], MDR[3], SMR[4] and AOMDV[1].
- We focus on AOMDV (Ad hoc On-demand Multipath Distance Vector), it guarantees loop freedom and link-disjoint paths.
- Back draws of AOMDV:
  - Doesn't use alternative paths simultaneously.
  - Use retransmission concept for reliability.
  - No Security support.

Future Work

- Approve the simulation results analytically.
- MSR against difficult attacks and environmental conditions.
  - Sybil and mobile/energy-aware.
- MSR performance optimization.
  - Use efficient routing metrics.
- MSR packet allocation optimization.
  - Weighted-k-out-of-n algorithm.

MSR Simulation Assumptions

- The sensor network is static.
- The sensor nodes are homogeneous.
- The communication channels are bidirectional.
- The deployment is random.

MSR: On-Demand Multipath Routing (cont.)

ROUTE_REQUEST packet format

sourceId	destinationId	requestId	hopCount	. . .

sourceId: the Id of the source node that originated the ROUTE_REQUEST.

destinationId: the Id of the destination node for which the route is desired.

requestId: a sequence number uniquely identifying the particular ROUTE_REQUEST when taken in conjunction with the sourceId and the destinationId.

hopCount: the number of hops from source node to the node handling the request.

MSR: On-Demand Multipath Routing (cont.)

ROUTE_REPLY packet format

sourceId	destinationId	requestId	hopCount	lifeTime	timeOut	...

sourceId: the Id of the source node that originated the ROUTE_REQUEST.

destinationId: the Id of the destination node for which the route is desired.

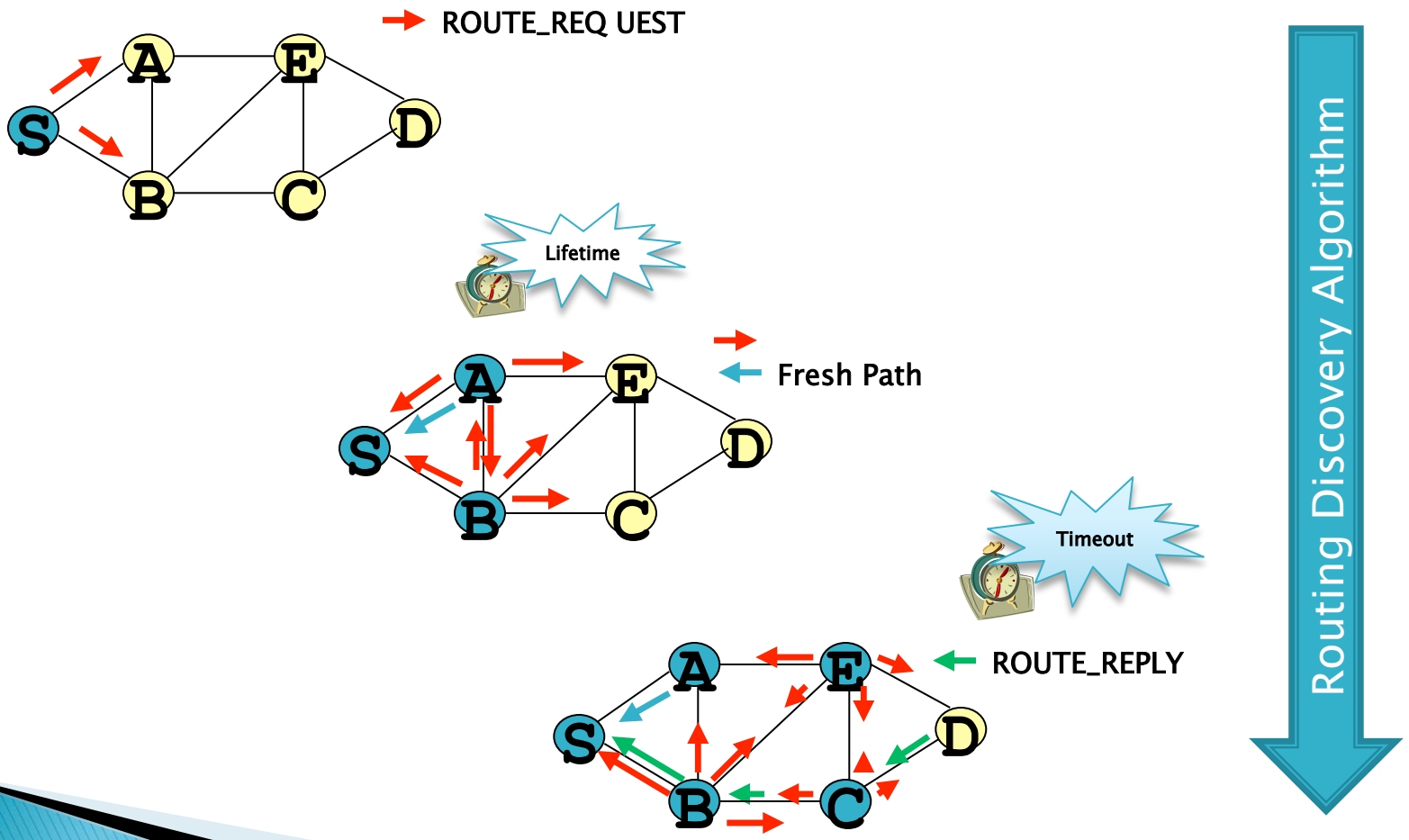
requestId: a sequence number uniquely identifying the particular ROUTE_REQUEST when taken in conjunction with the sourceId and the destinationId.

hopCount: the number of hops from source node to the node handling the request.

lifeTime: the time for which nodes receiving the ROUTE REQUEST consider the route to be valid.

timeOut: the time to discover the multipaths, starts from the arrival of the first ROUTE REPLY and waiting for this timeOut period to stop receiving any extra replies.

MSR: On-Demand Multipath Routing (cont.)

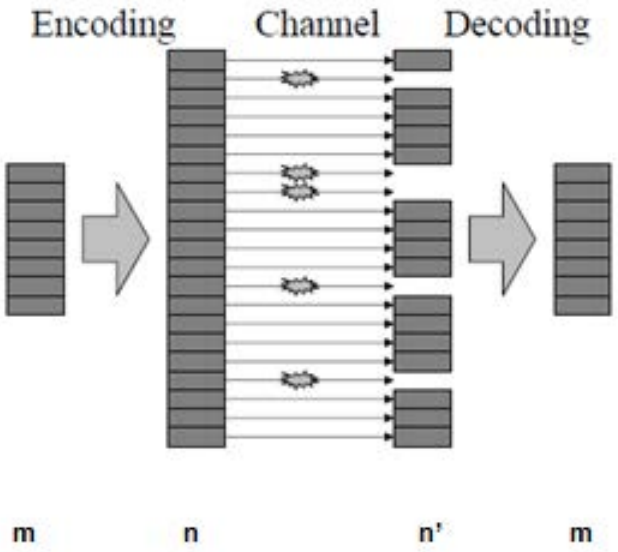


MSR: On-Demand Multipath Routing

- The on-demand multipath route discovery process as follow:
  - When a node needs a route to a destination, it broadcast a ROUTE-REQUEST.
  - Any node with a current route to that destination, can unicast a ROUTE-REPLY back to the source node.
  - Route information is maintained by each node in its routing table.
  - Information obtained through ROUTE-REQUEST and ROUTE-REPLY packets is kept with other routing information in the route table.

Splitting Method using Erasure Coding

- Erasure coding provides an efficient option for achieving **reliability** against the noisy channel and efficient data **replication** without end-to-end retransmission [16].



Splitting Method using Erasure Coding (cont.)

- In erasure coding, selecting an optimal value of the encoding code rate r, where $r = n/m$ is a critical issue. In general the larger it is, the more reliability we can achieve but with the more overhead as well!

Security Check via Enhanced Passive Acknowledgment

- A consistent dropping of a packet from a neighbor can be used as a sign of a blackhole attack [23].
- A partial dropping of a packet from a neighbor can be used as a sign of a selective forward attack [23].
- Packet headers can be checked to detect any malicious changes in the headers. This can be used to detect spoofing.
- The packet content itself can be analyzed to detect any unauthorized changes to the packet.

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- Contribution.
- Background.
- Related Work.
- MSR: A Multipath Secure Reliable Routing Protocol for WSNs.
- Scheme analysis.
- Experimental Results.
- Conclusions.
- Future Work.
- Objectives Review.
- References.

Background

- Security requirements.
- Attacker models.
- Erasure coding.
- Passive acknowledgment.

Background – Security Requirements

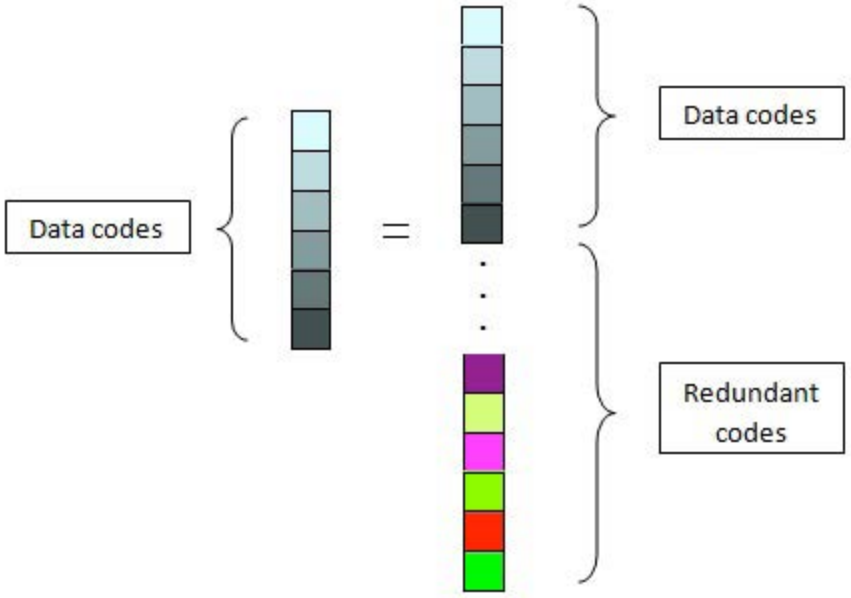
- Authentication.
- Availability.
- Confidentiality.
- Integrity.
- Freshness.

Background – Attacker Models

- Mote-class versus laptop-class.
- Passive versus active.
- Outsider versus insider.

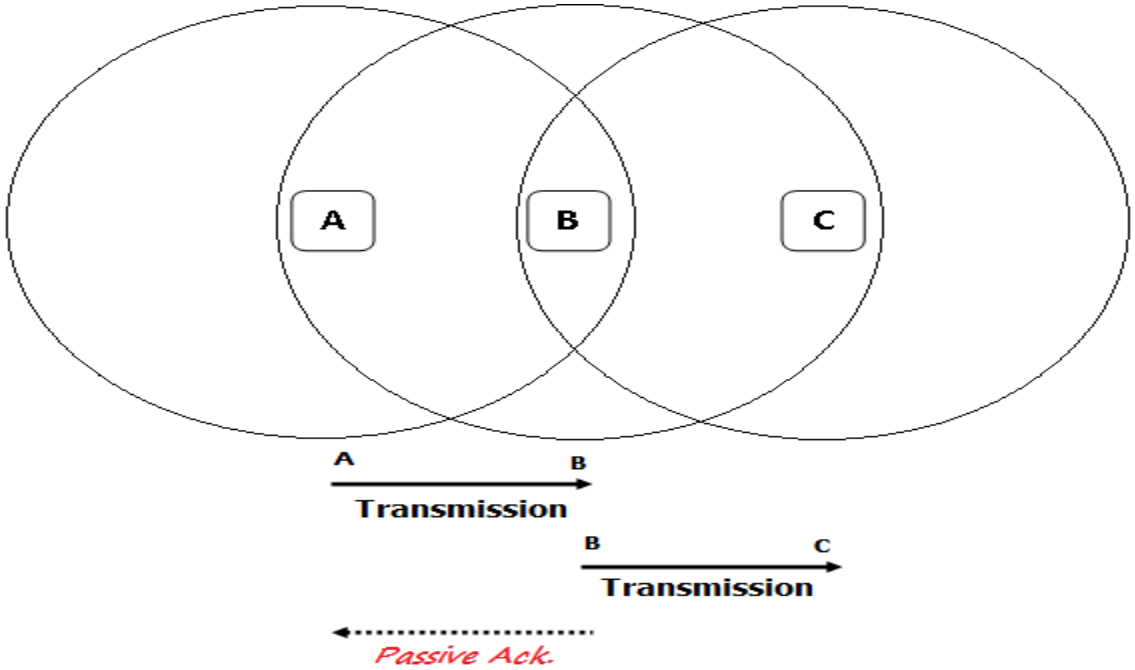
Background – Erasure Coding

- Erasure coding is a forward error correction (FEC) code for the binary erasure channel, which transforms a message of m blocks into a longer message with n blocks (codeword) such that the original message can be reconstructed from a subset of the n symbols. The fraction r=m/n is called the code rate.



Background – Passive Acknowlegdement

- Passive Acknowledgment (PACK) refers to the sender passively listen after finishing the message transmission to confirm that the message has been received by the destination (indirect overhearing).

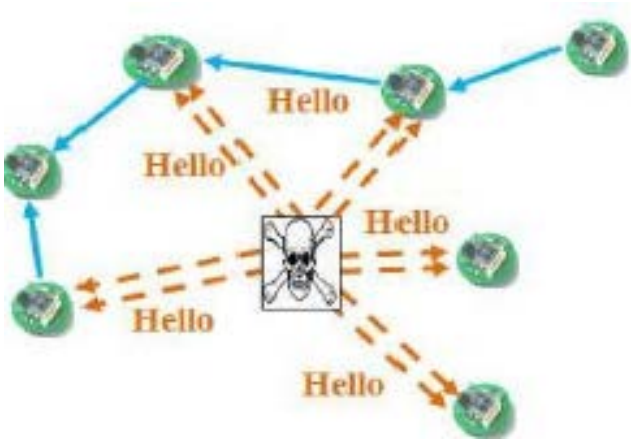


Assumption

- The network is static.
- The sensor nodes are homogeneous.
- The communication channels are bidirectional.
- The deployment is random
- Each sensor node has a unique Id.
- An attacker is assumed to be a mote-class, insider, and active.

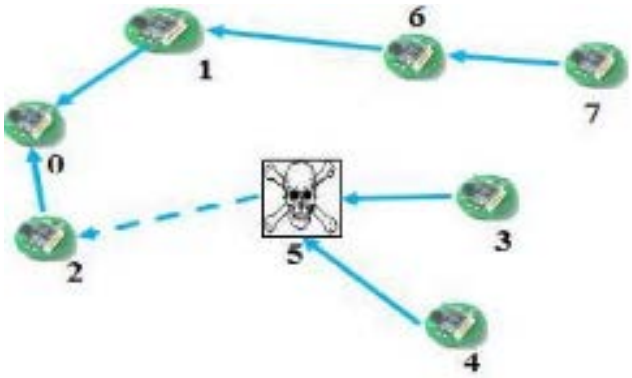
Security Analysis

- Security Attacks Definitions in WSNs:
  - Hello flood attack: a laptop-class adversary broadcasting routing information with large transmission power could convince every node in the network that the adversary is its neighbor.



Security Analysis (cont.)

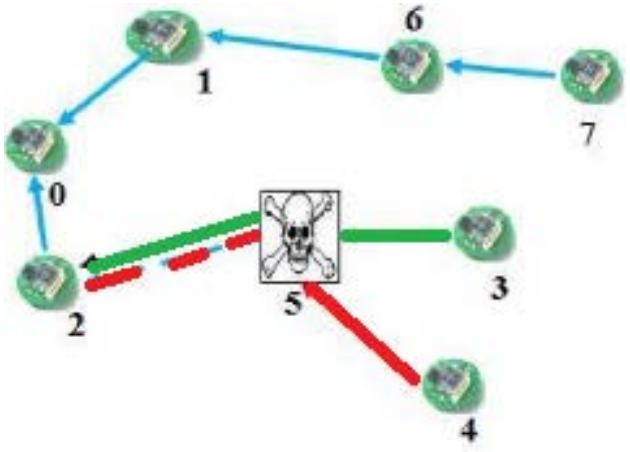
- **Security Attacks Definitions in WSNs:**
  - **Blackhole attack**: when a malicious node drops all the packets through it.



Security Analysis (cont.)

- Security Attacks Definitions in WSNs:

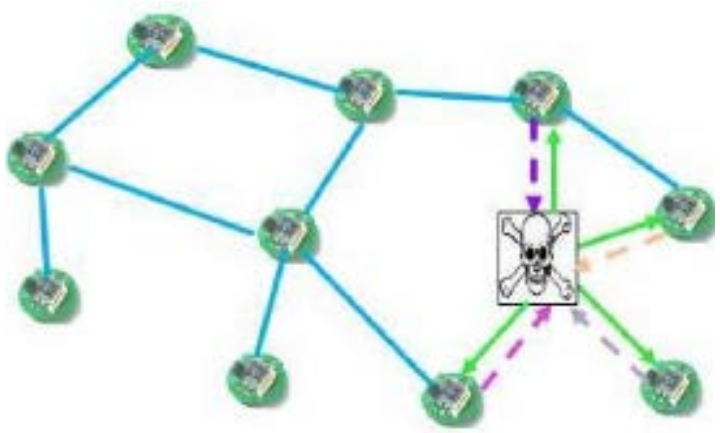
- Selective forward attack: when a malicious node can however drop or forward certain messages (it selectively forward the packets).



Security Analysis (cont.)

- Security Attacks Definitions in WSNs:

- **Acknowledgment spoofing attack**: when a malicious node spoofs an acknowledgment convincing the sender that a weak link may be strong or a dead node is alive.



Security Analysis (cont.)

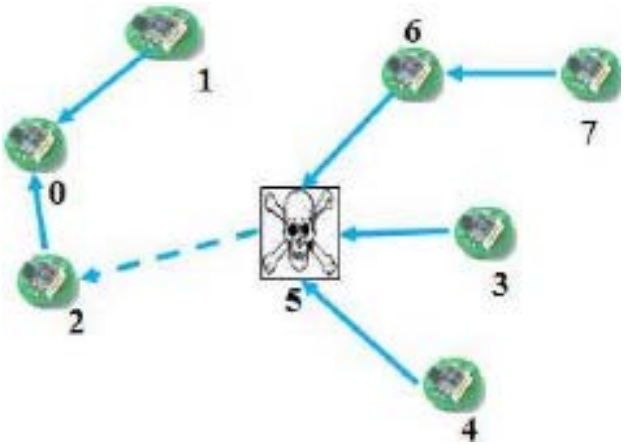
- Security Attacks Definitions in WSNs:

- Replay, alter and spoofing attacks: Adversaries are retransmitted the valid data repeatedly to inject the network routing traffic. They may be able to attract or repel network traffic, extend or shorten source routes, generate false error messages, partition the network, and increase end-to-end latency.

Security Analysis (cont.)

- Security Attacks Definitions in WSNs:

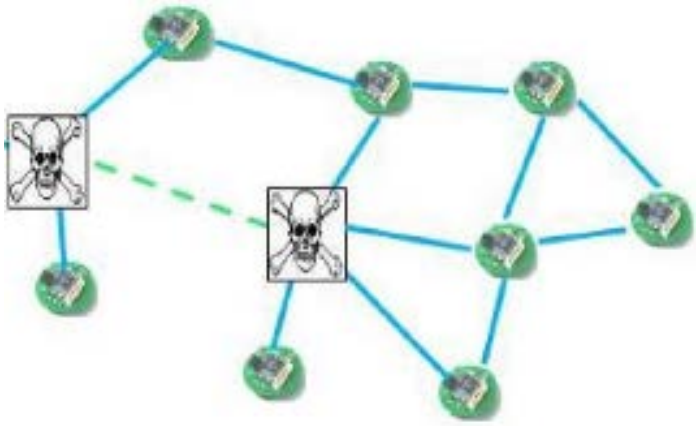
- Sinkhole attack: An adversary tries to attract almost all the traffic toward the compromised node. (The path presented through the malicious node appears to be the best available route for the nodes to communicate)



Security Analysis (cont.)

- Security Attacks Definitions in WSNs:

- Wormhole attack: An adversary tunnels messages received in one part of the network over a low latency link, to another part of the network where the messages are then replayed. (Wormholes are dangerous because they can do damage without even knowing the network.)



Security Analysis (cont.)

- Security Attacks Definitions in WSNs:

- Sybil attack: a single adversary node presents multiple identities to all other nodes in the WSN, which may affect data aggregation, voting or disjoint path routing.