SR3: Secure Reputation-based Resilient Routing

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Outline

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Challenges of secure routing in WSN

Security for routing in wireless sensor networks is hard, but necessary:

- Low memory, computing power, energy consumption
- Wireless medium is inherently vulnerable
- Compromise nodes: easy

Two main types of attacks

Packet-level attacks, *e.g.*

- Data messages alteration
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Our protocol is resilient against this type of attacks

Resiliency "Capacity of a network to endure and overcome internal attacks" [EOKMV11]

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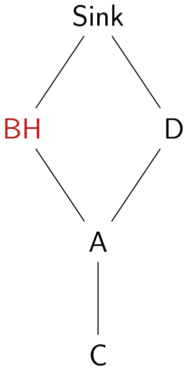
Main ideas

SR3: Secure Reputation-based Resilient Routing

- Convergecast routing from all sensors to the sink (server)
- Reinforced random walk
  - Built with a reputation mechanism
  - Based on unconditionally trusted information

SR3: Overview



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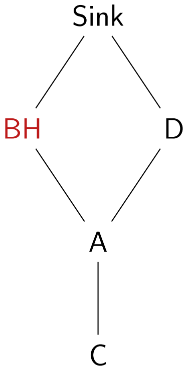

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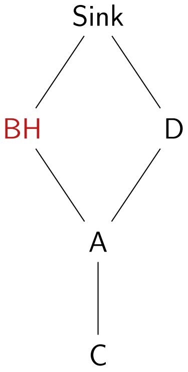

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- The sink answers with an ACK that tries to follow the reverse of the path of the message.
- If A gets a valid ACK, it increases its confidence in the neighbor who previously routed the corresponding message.

SR3: Packet-level attacks

Messages: $\mathcal{E}_{k_{src}}(Data||N), \mathcal{H}(N), Src$

ACK: N, Src

- Attacker who listens to the data
- Attacker who replays acknowledgements
- Attacker who alters or creates messages
- Attacker forging ACKs

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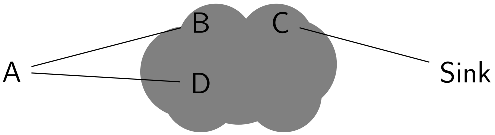
- Attacker forging ACKs
  → Keep the nonce secret until delivery, and reveal it in the ACK

SR3: Keep track of messages using L_{Queue}

- When A generates a new message with a nonce N, it chooses the next hop B, and stores a trace of this choice in L_{Queue}, a bounded size FIFO list.



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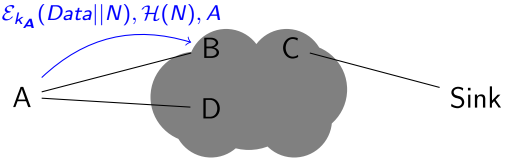

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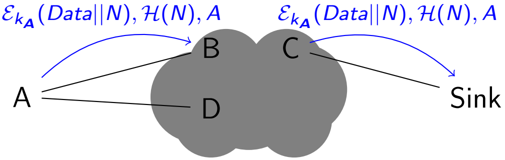

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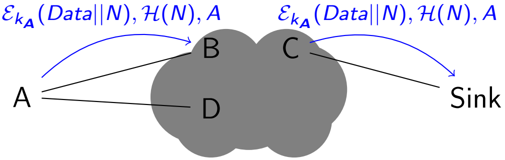

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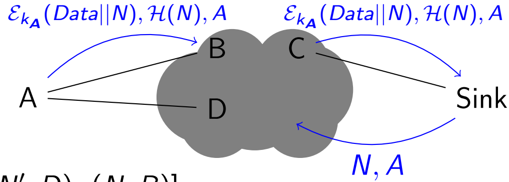

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- When A generates a new message with a nonce N, it chooses the next hop B, and stores a trace of this choice in L_{Queue}, a bounded size FIFO list.
- Upon reception of an ACK which contains N,
  - If A is not the final destination for that ACK, A routes it,
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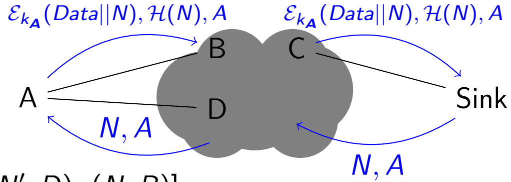

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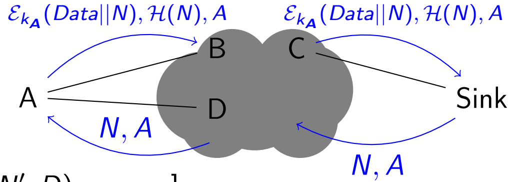

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SR3: Reputation

- Trust in a node is the number of identifiers of that node in a bounded FIFO list, $L_{Routing}$, initially empty.
- Messages are routed probabilistically according to the node's $L_{Routing}$.

$$Pr(X = n) = \frac{|L_{Routing}|_n + \delta_v^{-1}}{|L_{Routing}| + 1}$$

F's $L_{Routing}$, max size = 3 :
[, ,] $(\star)$

$$P(X = C) = \frac{0 + 0.5}{1} = 50\%$$

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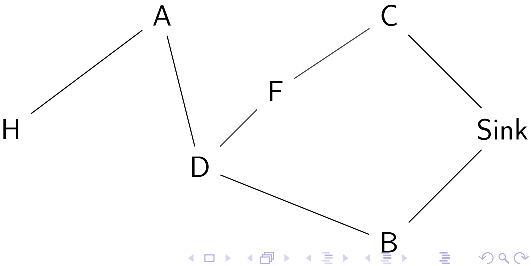

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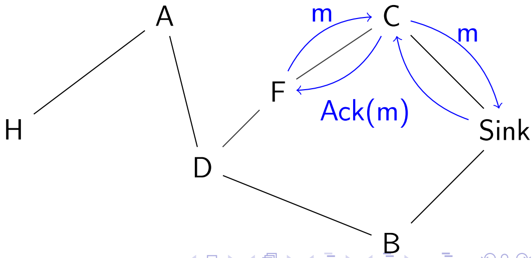

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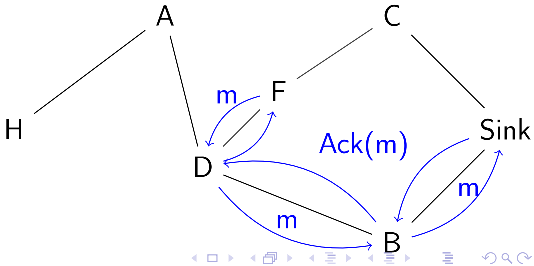

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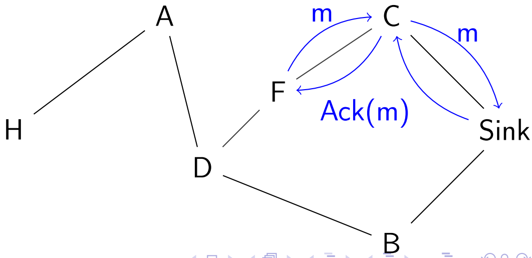

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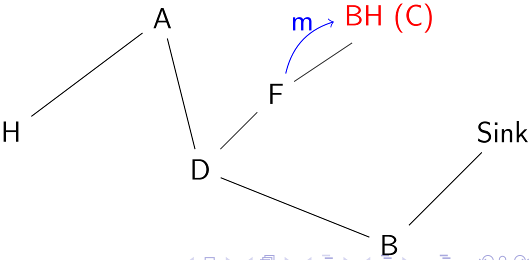

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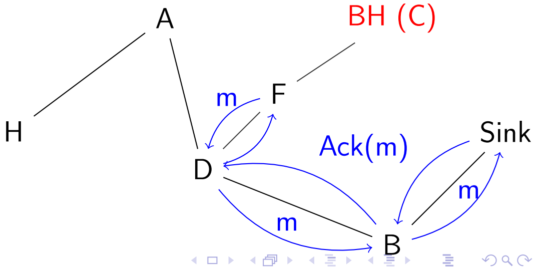

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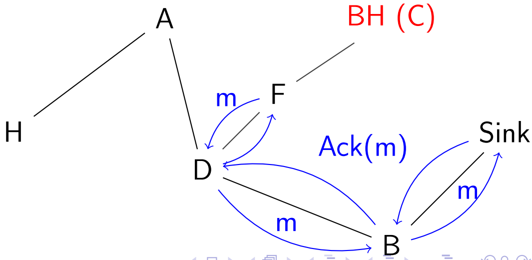

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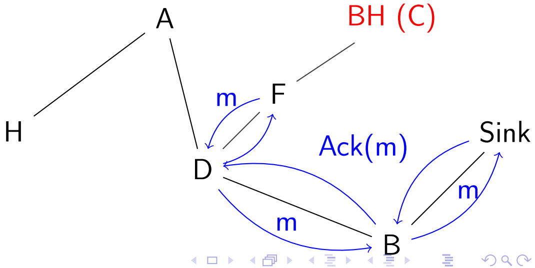
$$P(X = C) = \frac{0 + 0.5}{4} = 12\%$$

$$P(X = D) = \frac{3 + 0.5}{4} = 88\%$$



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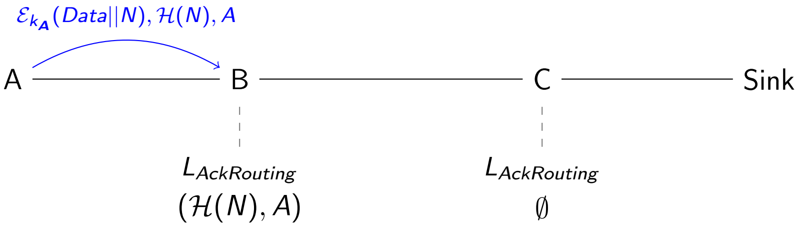

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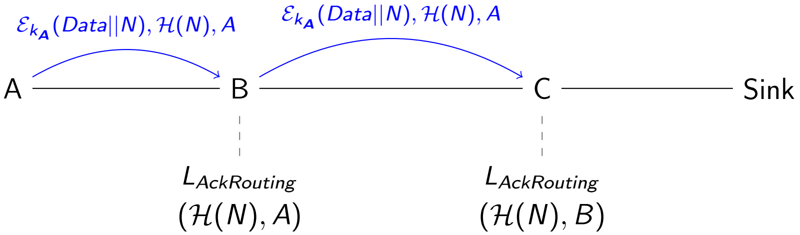

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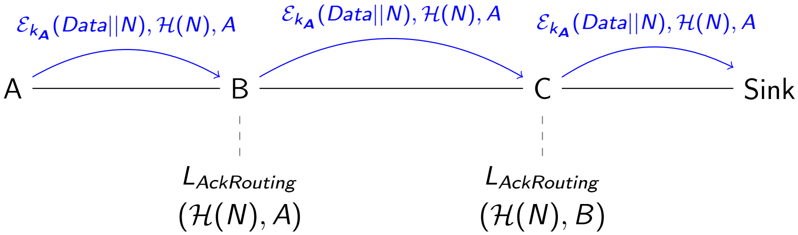

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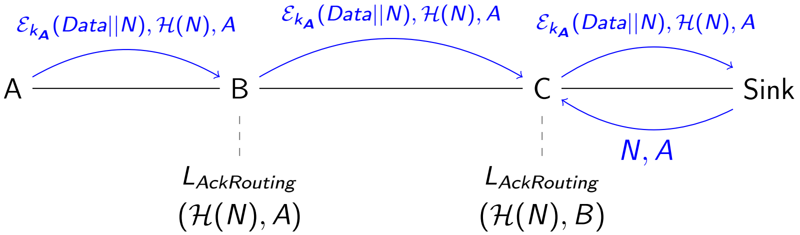

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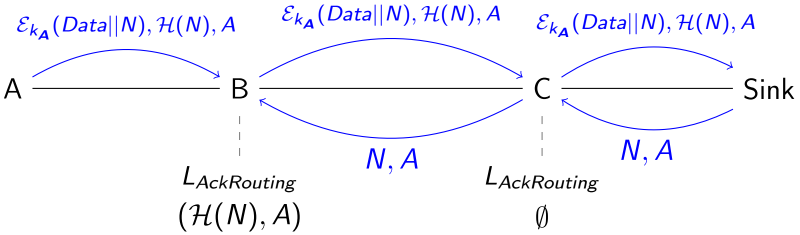

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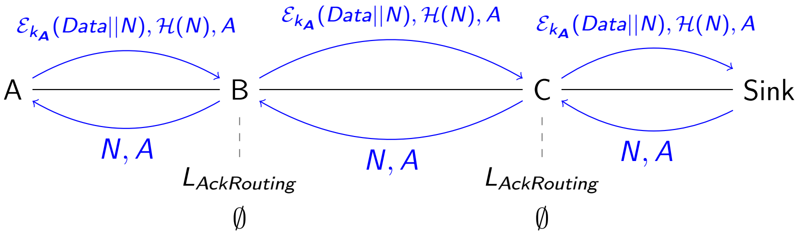
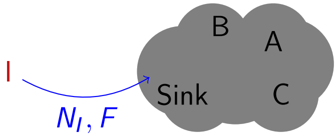


Lost and forged acknowledgements



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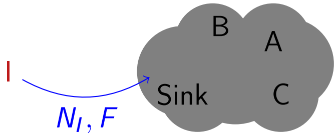

ACKs therefore have a $\frac{1}{Nb}$ probability of being dropped at each retransmission, with Nb an upper bound on the number of nodes.

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Security properties and proofs

- Nonce confidentiality before delivery
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Using game reductions, we are then able to find an upper bound on the advantage of any attacker, which we can then use to find the right compromise between costs and the level of security.

Modeling the protocol

Hash function

We model it as a random oracle $\mathcal{H} : \{0,1\}^{\eta_n} \rightarrow \{0,1\}^{\eta_h}$. The number of times the adversary calls $\mathcal{H}$ is denoted q_H.

Nonces

Nonces are modeled as truly random numbers of size η_n.

Block Cipher

A block cipher $\mathcal{F}$ is a set of permutations of $\{0,1\}^{\eta_c}$, indexed on keys. We assume that the block cipher is *PRP-CCA*-secure, which is the property we rely on for security.

$Gen_{src}^{\mathcal{O}(\cdot)}(Data)$

The function which generates a packet produced by *src* containing *Data*, using $\mathcal{O}$ as a block cipher, and drawing a new nonce N.

Data confidentiality

Let $\mathcal{A}$ be an adversary running in two phases ($\mathcal{A}_1$ and $\mathcal{A}_2$).

Experiment $\mathbf{Expt}_F^{FG}(\mathcal{A})$:

$k_{src} \xleftarrow{\$} Init(\mathcal{K})$

$(\mathcal{O}, \mathcal{O}^{-1}) \leftarrow (F_{k_{src}}, F_{k_{src}}^{-1})$

$(Data_0, Data_1, state) \xleftarrow{\$} \mathcal{A}_1^{Gen_{src}^{\mathcal{O}(\cdot)}(\cdot), \mathcal{H}(\cdot)}()$

$b \xleftarrow{\$} \{0, 1\}$

$(\langle C, h, src \rangle, N) \xleftarrow{\$} Gen_{src}^{\mathcal{O}(\cdot)}(Data_b)$

If $(b = \mathcal{A}_2^{Gen_{src}^{\mathcal{O}(\cdot)}(\cdot), \mathcal{H}(\cdot)}(\langle C, h, src \rangle, N, state))$

  Return 1

Else

  Return 0

Advantage and bounds

The find-then-guess advantage of $\mathcal{A}$ against F is defined as the probability of $\mathcal{A}$ winning the game (*i.e.* $Pr[\mathbf{Expt}_F^{FG}(\mathcal{A}) = 1]$) minus the probability of winning for an adversary that outputs a random bit:

$$\mathbf{Adv}_F^{FG}(\mathcal{A}) = Pr[\mathbf{Expt}_F^{FG}(\mathcal{A}) = 1] - \frac{1}{2}$$

We then use Cryptoverif [Bla07][1], an automated prover of cryptographic properties in the computational model, to get an upper bound on this advantage.

[1] `http://prosecco.gforge.inria.fr/personal/bblanche/cryptoverif/`

Advantage and bounds

For all adversaries $\mathcal{A}$ making q_G queries to *Gen* and q_H queries to the hash function, there exists an adversary $\mathcal{B}$ (making $q_G + 1$ queries to $\mathcal{O}$ in its game) such that:

$$\mathbf{Adv}_F^{FG}(\mathcal{A}) \leq \frac{2q_G^2 + 2q_G}{2^{\eta_c}} + \frac{2q_G^2 + 4q_G + 2}{2^{\eta_n}} + 2\mathbf{Adv}_F^{PRP-CPA}(\mathcal{B})$$

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From this, we can choose our parameters to achieve the desired security bound. For instance, if we use a $\eta_c = 128$b block cipher and a $\eta_n = 96$b nonce, and we allow the attacker $q_G = 2^{20}$ oracle calls and answers, we get:

$$\mathbf{Adv}_F^{FG}(\mathcal{A}) \leq \frac{2 \times (2^{20})^2 + 2 \times 2^{20}}{2^{128}} + \frac{2 \times (2^{20})^2 + 4 \times 2^{20} + 2}{2^{96}} + 2\mathbf{Adv}_F^{PRP-CPA}(\mathcal{B})$$

$$= ... = 2^{-54.999} + 2\mathbf{Adv}_F^{PRP-CPA}(\mathcal{B})$$

Choosing the block cipher and final bound

$$\mathbf{Adv}_F^{FG}(\mathcal{A}) \leq 2^{-54.999} + 2\mathbf{Adv}_F^{PRP-CPA}(\mathcal{B})$$

If we use AES-128 as block cipher, the best attack known to this day needs $2^{126.1}$ operations. Therefore, we can expect $\mathbf{Adv}_{AES-128}^{PRP-CPA}(\mathcal{B})$ to be much smaller than 2^{-54} for any adversary $\mathcal{B}$.

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$$\mathbf{Adv}_F^{FG}(\mathcal{A}) \leq 2^{-54.999} + 2\mathbf{Adv}_F^{PRP-CPA}(\mathcal{B})$$

If we use AES-128 as block cipher, the best attack known to this day needs $2^{126.1}$ operations. Therefore, we can expect $\mathbf{Adv}_{AES-128}^{PRP-CPA}(\mathcal{B})$ to be much smaller than 2^{-54} for any adversary $\mathcal{B}$.

- Using nonces of 12 bytes and hashes of 8 bytes,
- Using a correct blockcipher of 16 bytes (*e.g.* *AES*-128),
- With an attacker that has 2^{20} packets with chosen data, hash function calls, and validity queries,

The probability of the adversary breaking one of the three properties is less than 2^{-50}.

Outline

Comparison points

Protocols with different underlying mechanisms

- Uniform Random Walk
- Gradient Based Routing (GBR) plus variants built for enhanced resiliency [EOKMV11]
  - RGBR (randomly select a lower height neighbor each time)
  - PRGBR (send to the same height with $p = 0.4$)
  - PRDGBR (PRGBR + duplication at each node)
- Greedy-Face-Greedy (geographical)

Simulation parameters, models and topologies

- Sinalgo[2], from ETH Zurich
- Asynchronous network (FIFO links)
- Every honest node generates messages, random intervals
- From 50 to 400 randomly positioned sensors, one centered sink
- Topology: Unit Disk Graphs, average degree from 8 to 32
- Connectivity: connected graphs only
- Overall, around 15k simulations, sending over 6 billion messages.

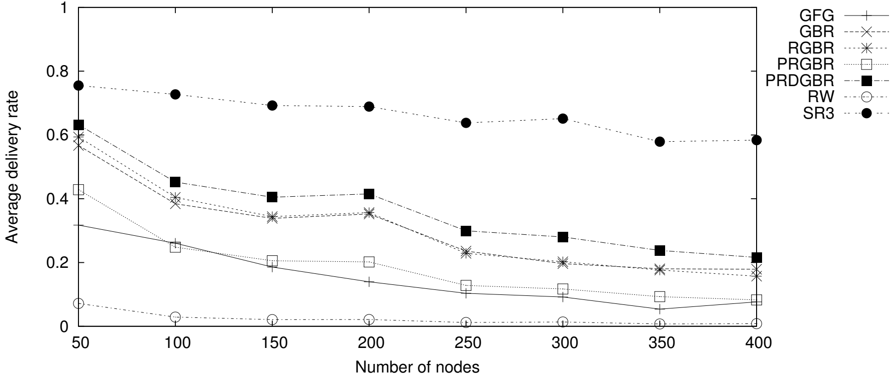
[2] `http://www.disco.ethz.ch/projects/sinalgo/`

Chosen attacks

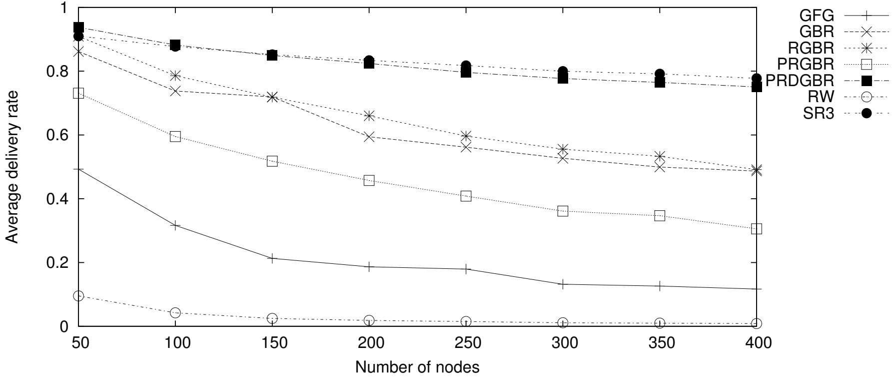
- Safe networks
- Blackholes (10%, 20% and 30%)
- Selective forwarding (10% and more, overall less impact than blackholes)
  - From 0 to 100% of messages transmitted
- 5% Wormholes→Blackholes + 5% Blackholes
  - Direct link to the sink, switch behaviors at one third of the simulation
- Sybil nodes (10% and more, not significantly better than blackholes)
  - From 1 to 5 identities

All attackers are randomly positioned.

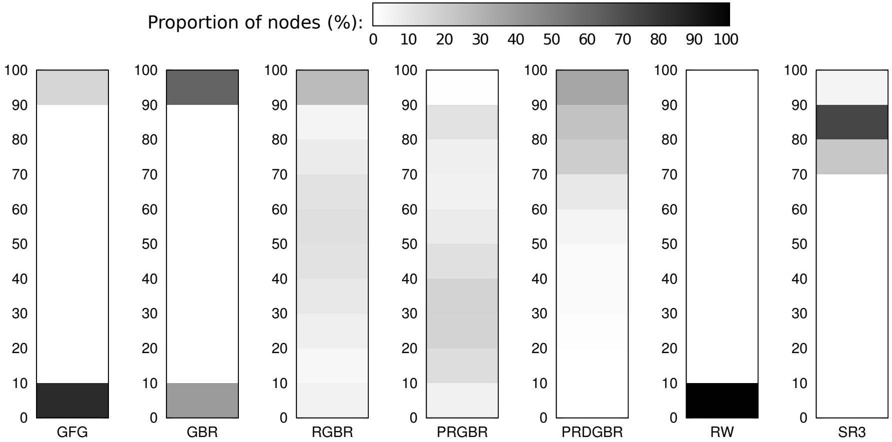
30% Blackholes, degree 8



30% Blackholes, degree 32

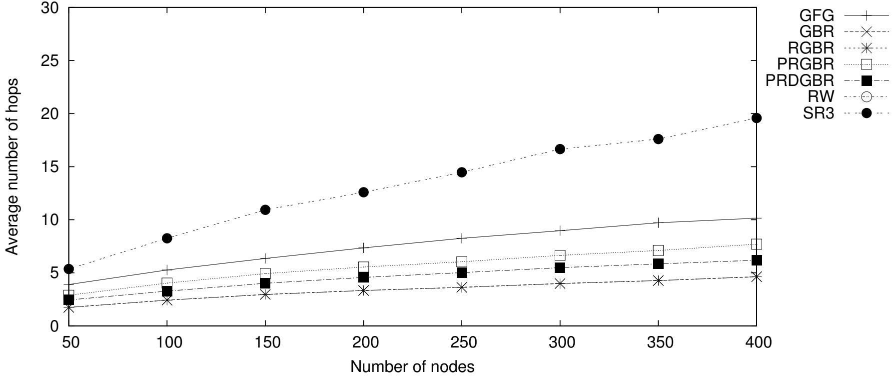


30% Blackholes, degree 32, 200 nodes



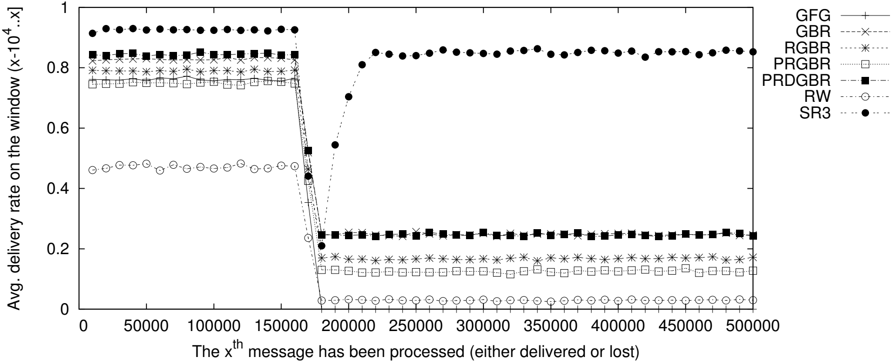
Distribution of the delivery rate (in %) for each node

No attackers, degree 16



For 400 nodes, RW is around 600 hops.

5% WH->BH, 5% BH, 200 nodes, degree 8, over time



Outline

Conclusion and future work

- SR3, Secure Reputation-based Resilient Routing
- Proved secure packet format using CryptoVerif
- Resilient against multiple attacks
- Efficient algorithm on both small (<50 nodes) and large (>400 nodes) networks

Future works:

- Dynamicity and mobility of nodes
- Implementation and energy measurements planned in ARESA2

Thanks for your attention.

Questions ?

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http://www-verimag.imag.fr/~rjamet/SR3/

Bibliography

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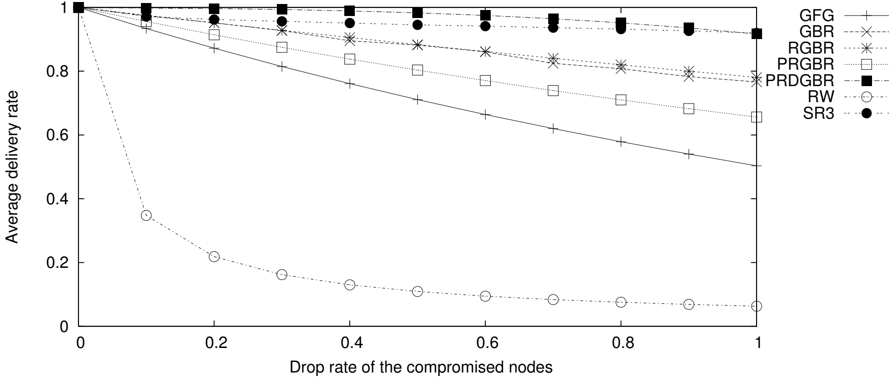
O. Erdene-Ochir, A. Kountouris, M. Minier, and F. Valois, *Enhancing resiliency against routing layer attacks in wireless sensor networks: Gradient-based routing in focus*, International Journal On Advances in Networks and Services 4 (2011), no. 1 and 2, 38–54.

20% Selective Forwarding, 200 nodes, degree 8, varying p



10% Sybil, 200 nodes, degree 8, varying number of identities