Hiding the Base Station in WSNs

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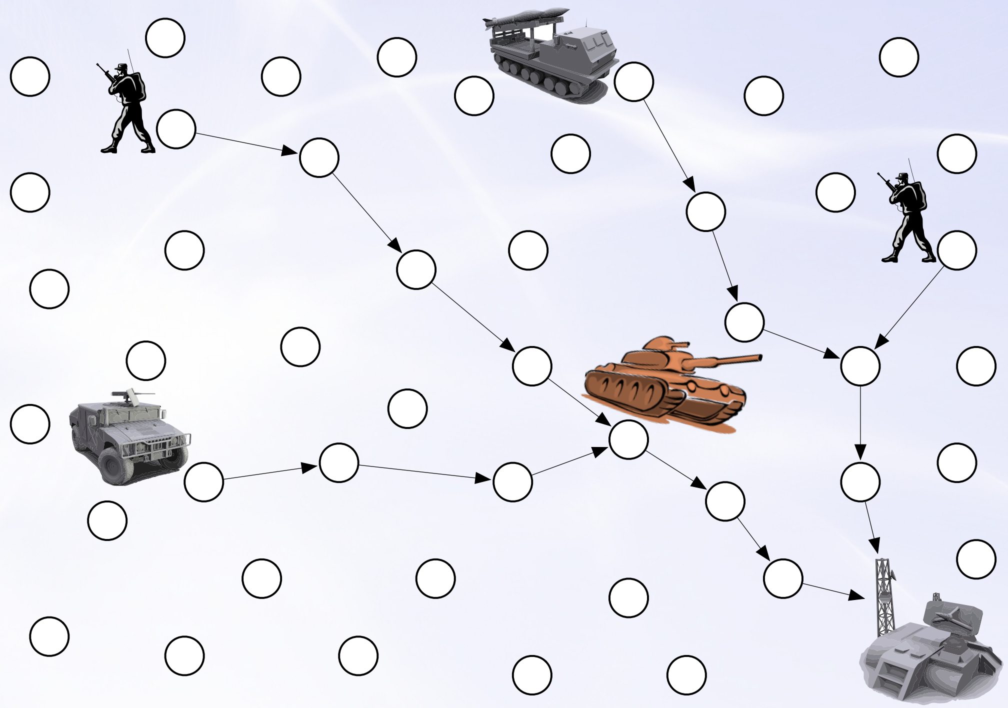
Motivation

- Receiver-location privacy is concerned with hiding the location of the BS
  - Physical protection
  - Strategic information

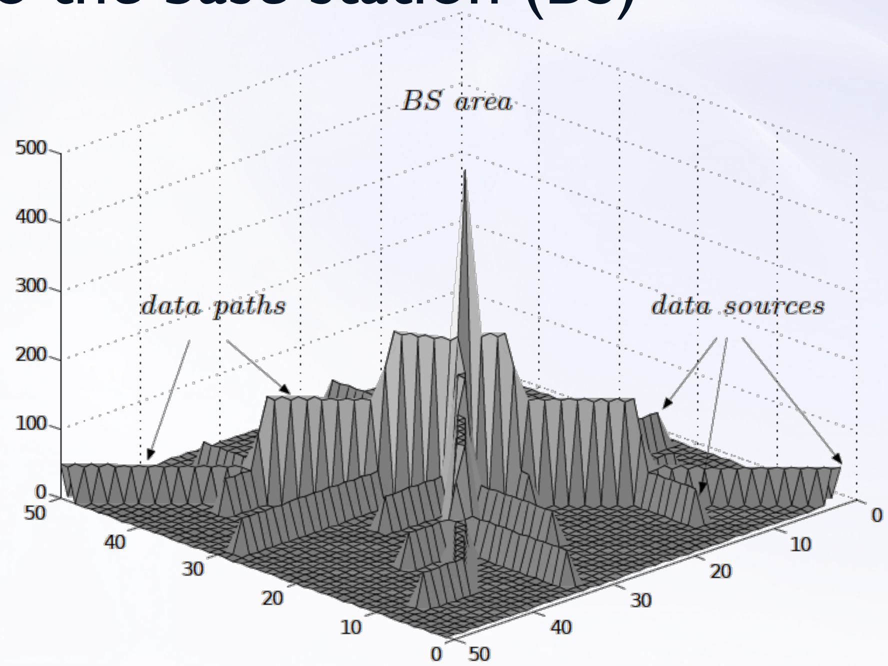


- These problems are extensible to any WSN scenario (e.g., sealife monitoring, smart metering, etc.)

Motivation

- WSN solutions are designed to maximize the lifetime of the network
  - Data is transmitted using single-path routing algorithms as soon as an event is detected

- Routing protocols introduce pronounced traffic patterns because all the data is address to the base station (BS)
  - Nodes transmit shortly after receiving a packet
  - Traffic volume is higher as we approach the BS



Agenda

- Motivation
- Problem Statement
- Hiding Scheme
- Evaluation
- Conclusion

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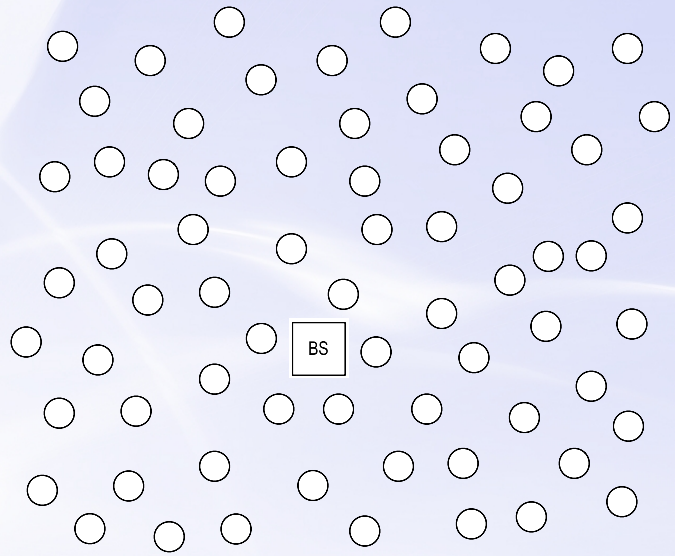
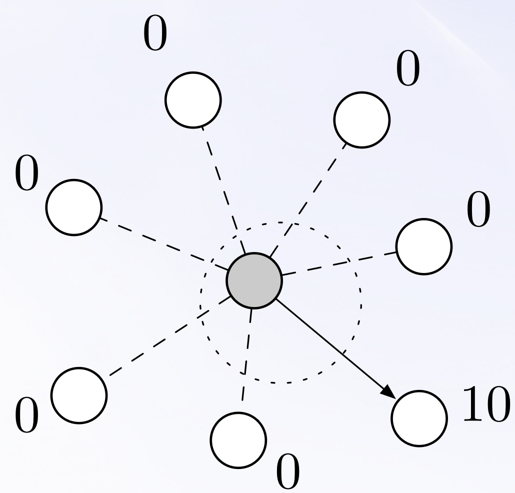
Problem Statement

- Network model
  - Vast deployment area
  - Densely populated network
  - A single base station
  - Event-driven monitoring application
  - Sensor nodes share cryptographic keys



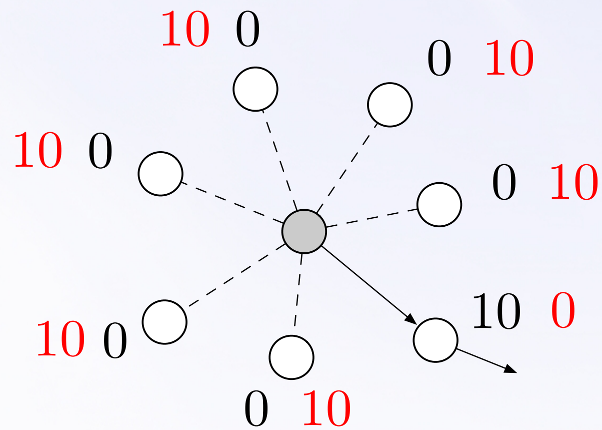
- Adversary model
  - Passive eavesdropper with local vision
  - Cannot decrypt messages
  - Cannot distinguish real from bogus traffic
  - Can move in the field based on
    - Time-correlation (flow direction)
    - Rate-monitoring (traffic volume)
  - Can capture a portion of the nodes



Data transmission

- The idea is to locally homogenise the number of packets sent by a node to its neighbours such that
  - Real traffic reaches the BS
  - The attacker gains no information

- Whenever a node has to transmit, it sends two messages
  - Real message: follows a biased random walk
  - Fake message: must serve as traffic normaliser



Data transmission

- We require three properties to ensure the usability (*Prop 1*) and security (*Prop* 2, 3) of the system

  - *Prop 1:* Convergence

$$E(dist(x', BS)) < E(dist(x, BS))$$

  - *Prop 2*: Homogeneity

$$\forall y, z \in neigh(x) \quad Frec_m(x, y) \simeq Frec_m(x, z)$$

  - *Prop 3*: Exclusion

$$\forall m, m', x, y, t \quad send(m, x, y, t) \wedge m \neq m' \Rightarrow \neg send(m', x, y, t)$$

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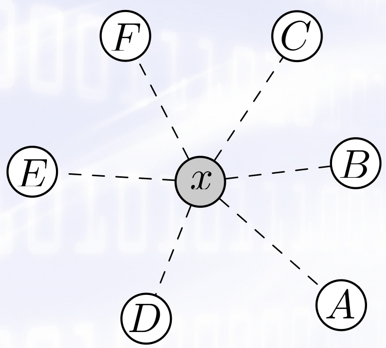
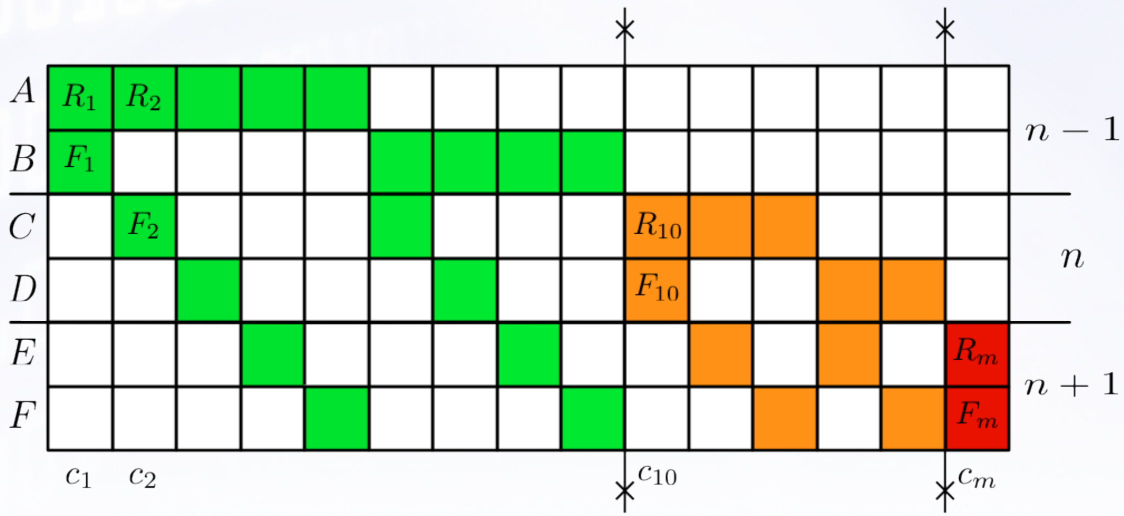
Data transmission

- The previous properties can be ensured by means of a computationally inexpensive approach
  - Sorted combinations without repetition of two neighbours
  - Select one of the combinations uniformly at random



neighs(x)	distance
A	$n-1$
B	$n-1$
C	n
D	n
E	$n+1$
F	$n+1$



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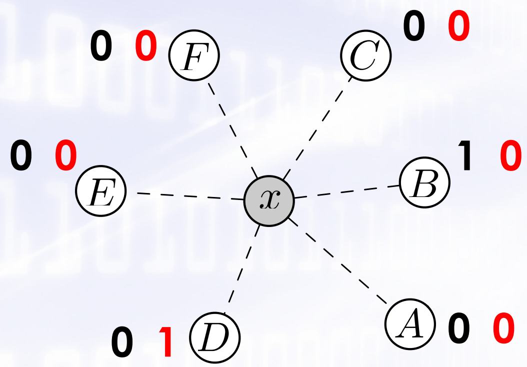

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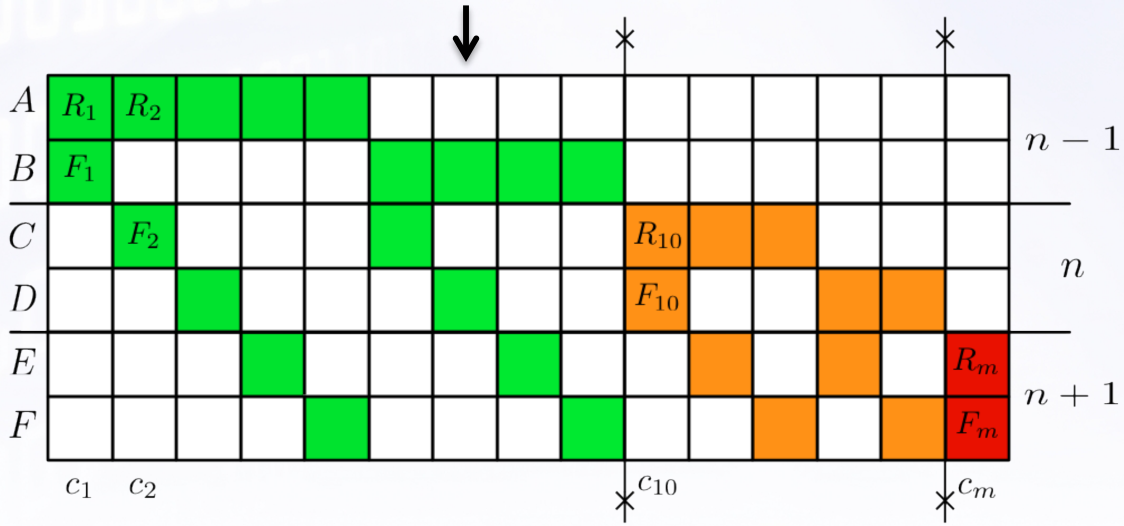

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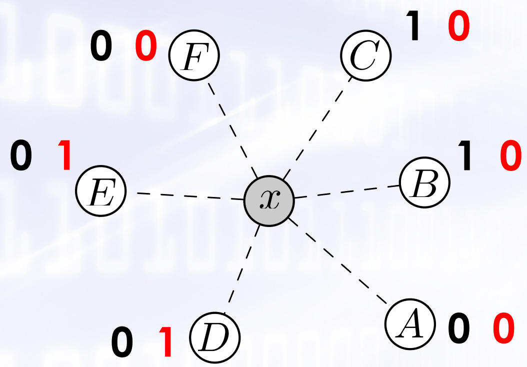

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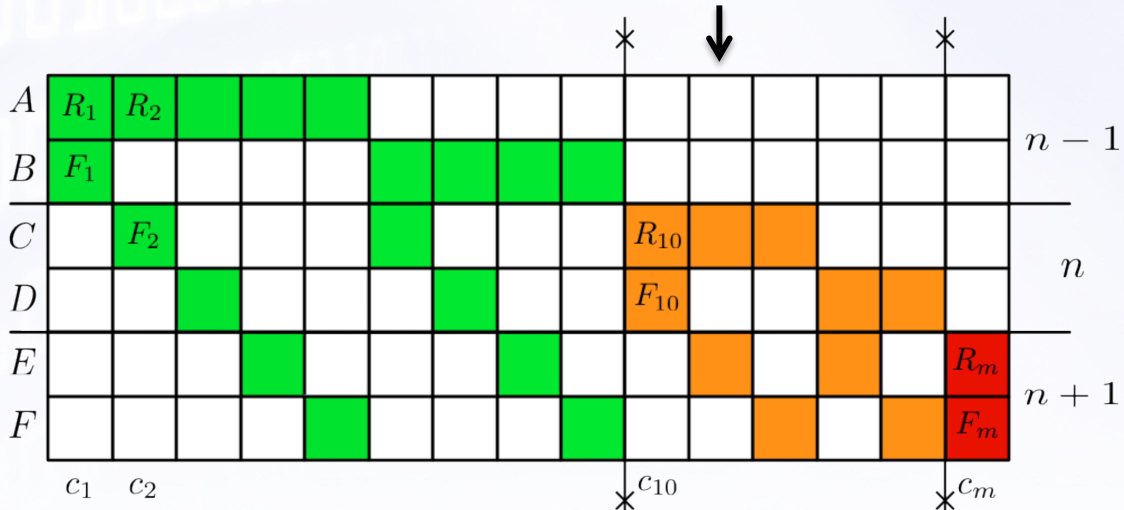

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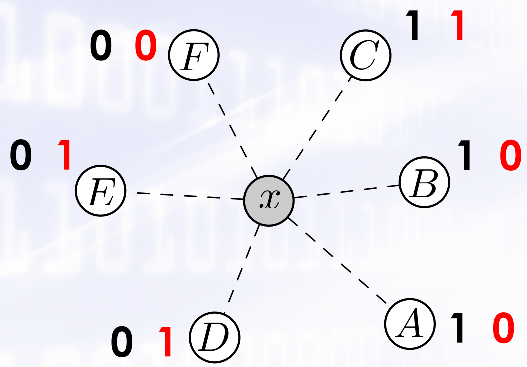

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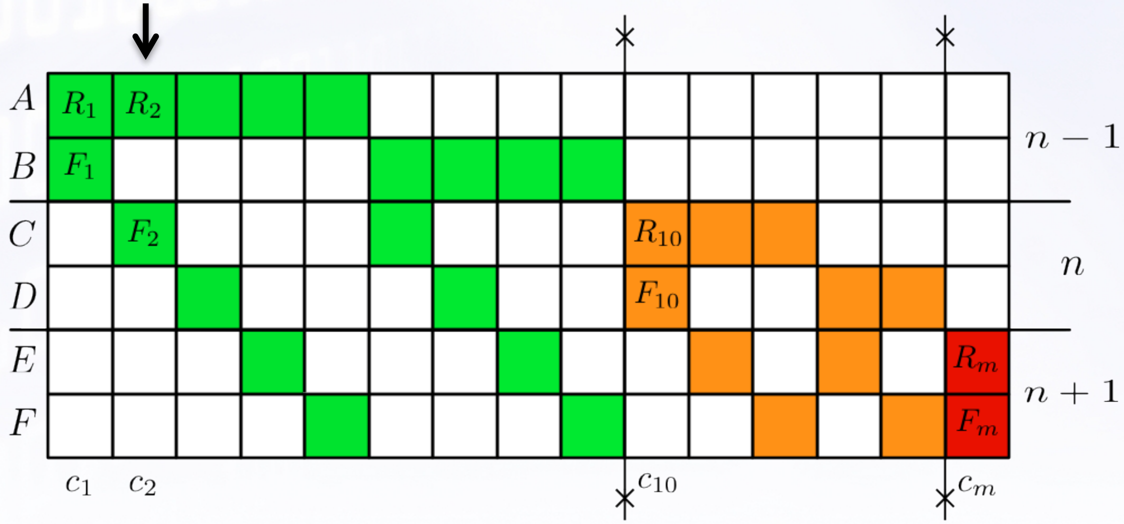

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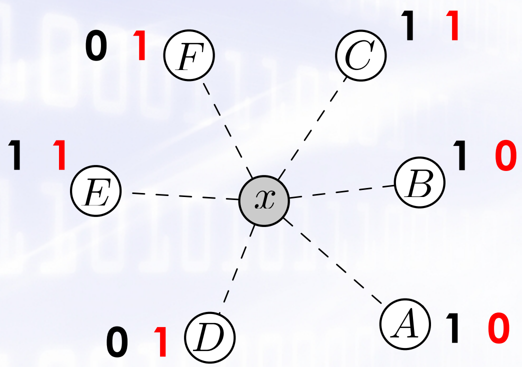

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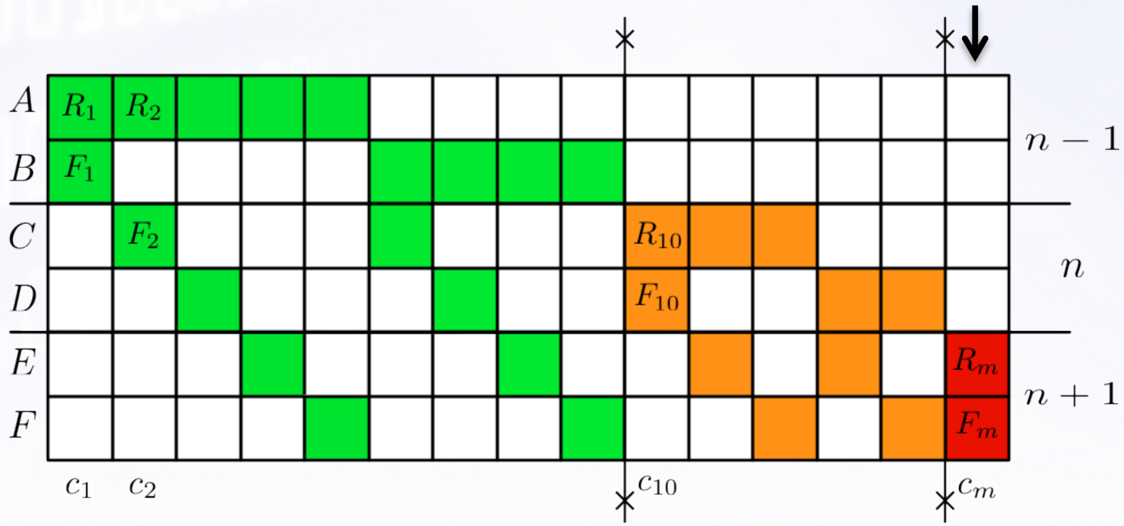
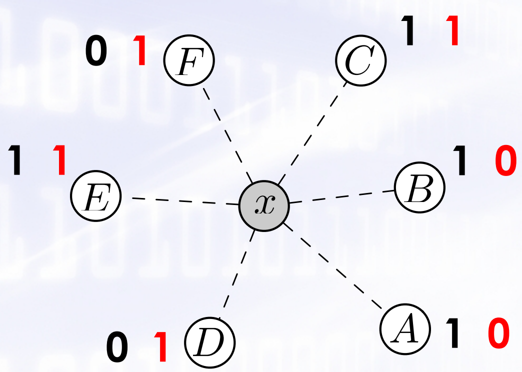


Data transmission

- Every nodes receives, on average, the same number of packets
- Real traffic has been most likely transmitted to nodes closer or at equal distance (A,B, C) to the base station
  - Although some nodes further (E) might also receive real traffic



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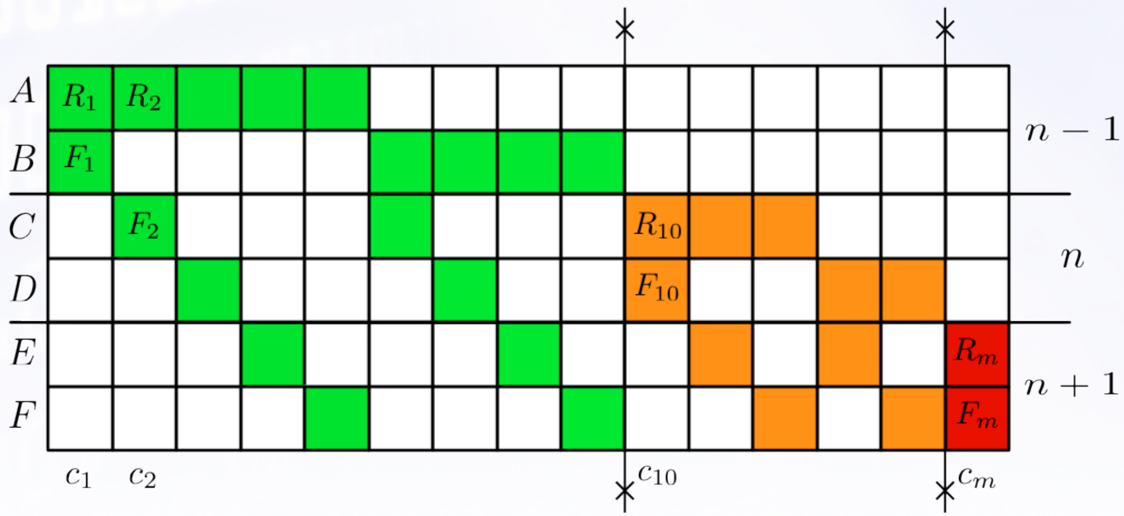
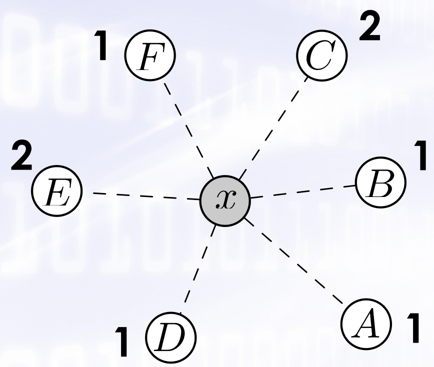


Data transmission

- Moreover, recall that the attacker cannot distinguish real from bogus traffic
  - Therefore, what the attacker sees locally gives him no information about the direction to the base station



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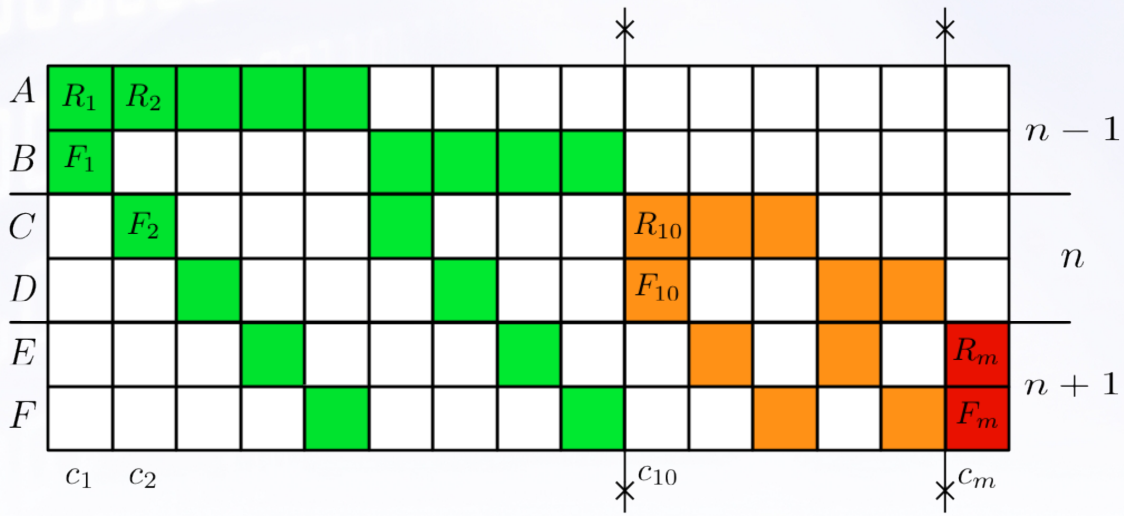
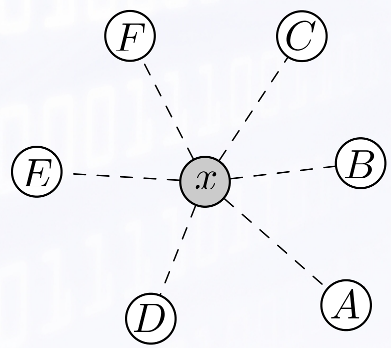


Node Compromise

- However, this protection mechanism becomes useless if the attacker has direct access to the routing tables of the node
  - Node capture attacks are likely due to the unattended nature of WSNs

- Routing tables are sorted ($L^{\mathcal{C}}$, $L^{\mathcal{E}}$, $L^{\mathcal{F}}$) to allow the data transmission protocol to ensure the Convergence Property
  - Leaks the direction to the BS



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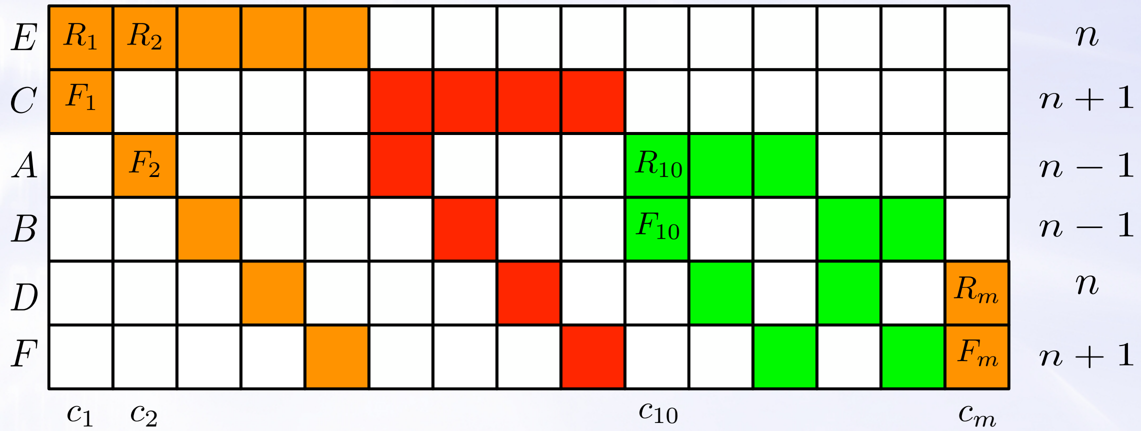
Node Compromise

- We introduce a routing table perturbation scheme that re-arranges the elements of the table
  - Still ensure that Prob(n $\in L^C$) > Prob(n $\in L^F$)

neighs(x)	distance
C	n
E	$n+1$
A	$n-1$
B	$n-1$
D	n
F	$n+1$



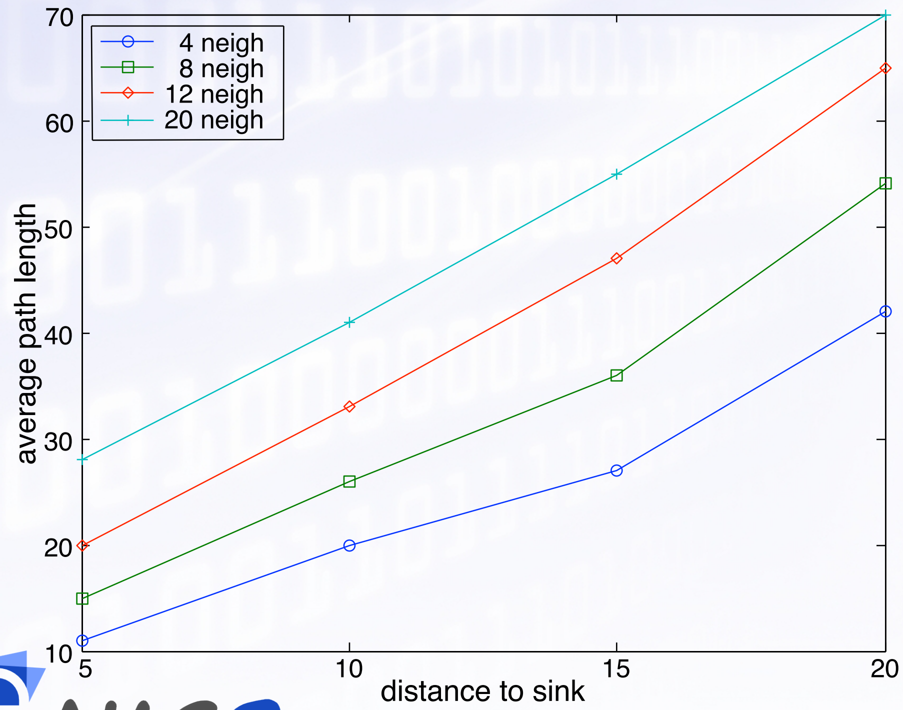
- An optimisation algorithm is used to perturb the tables to a desired degree (bias $\in$ [-1,1])
  - Trade-off between security and delivery time

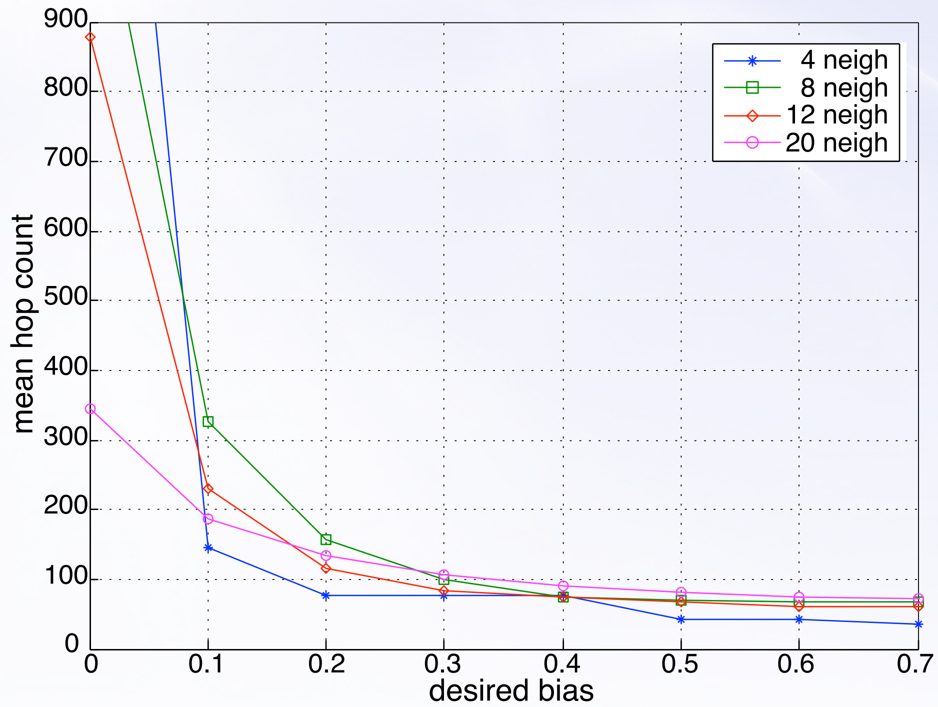
Evaluation: Usability

- Message delivery time is affected by the probabilistic nature of the protocol

$$x_n = 1 + px_{n-1} + qx_n + rx_{n+1}$$

- The routing table perturbation mechanism also impacts negatively on the delivery time
  - Hop count is below 100 for a bias greater than 0.2





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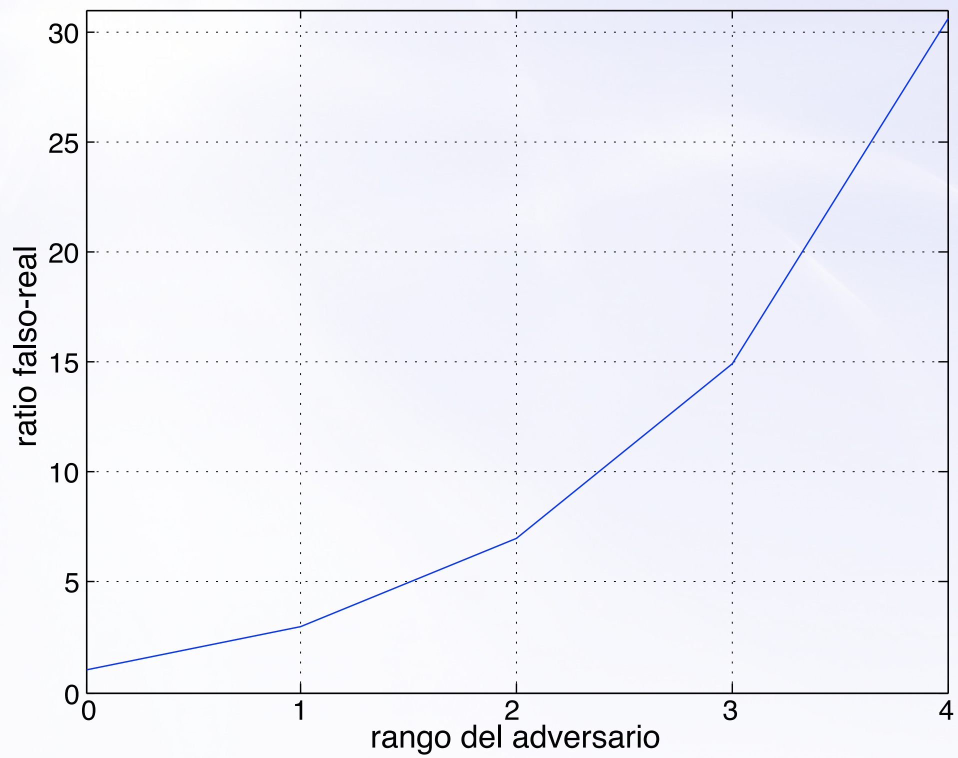
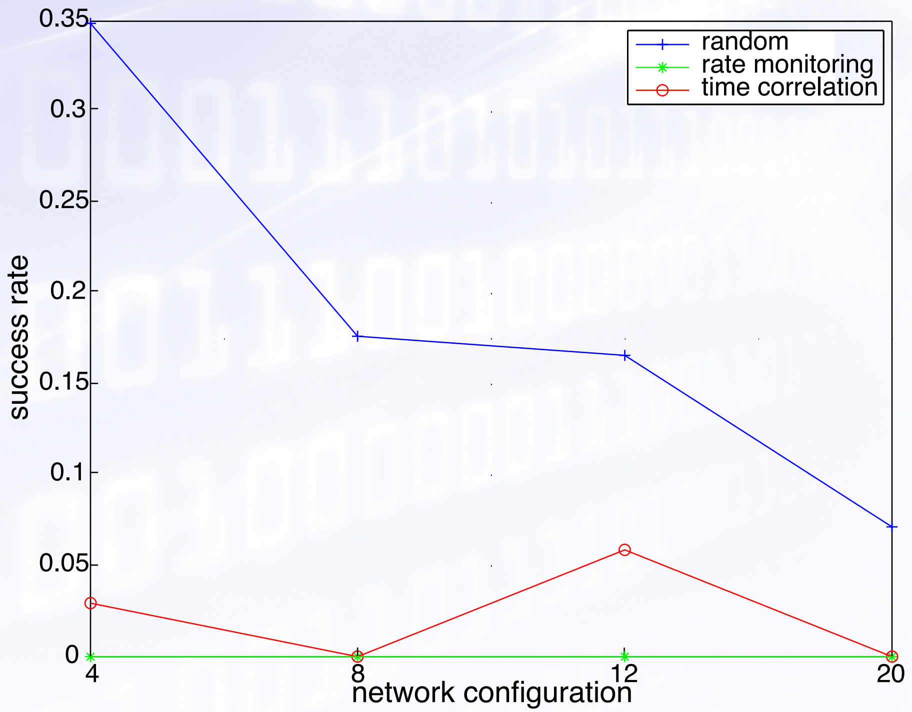
Evaluation: Usability

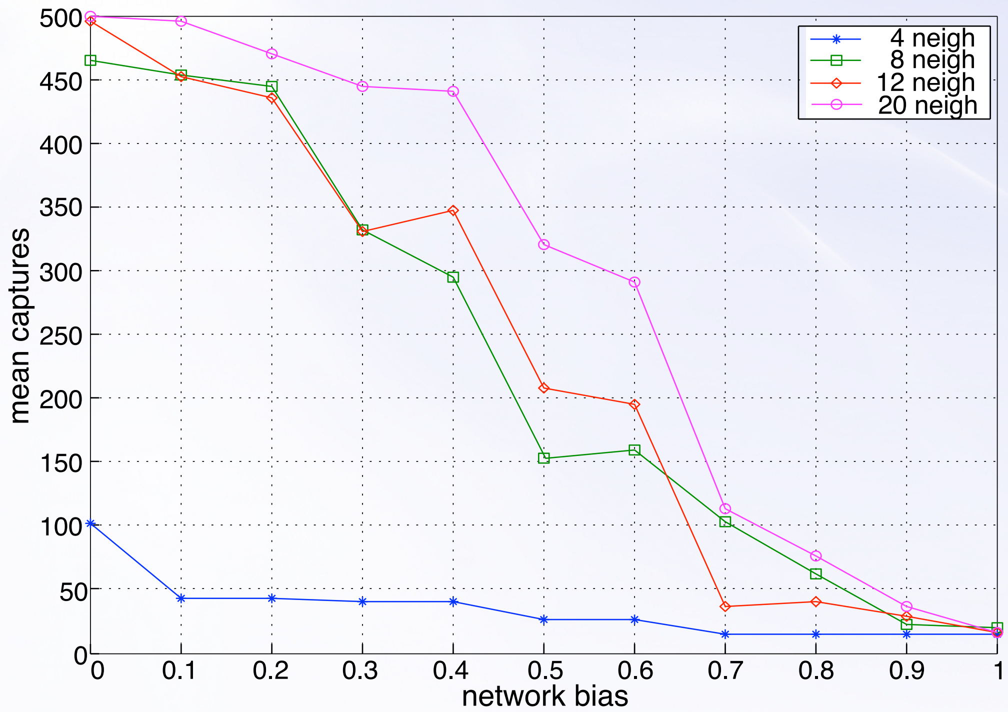
- The use of fake traffic impacts on the network lifetime
- The durability of fake traffic is controlled by a parameter, which is dependent on the hearing range (n) of the adversary
  - Discarded after several hops
- The hearing range of a typical adversary is $n=1$ (local adversary)



Evaluation: Privacy

- We have verified the privacy protection level of our solution for different types of adversaries
  - Passive eavesdroppers should better move at random
  - Active attackers must capture more than 1/10 of nodes to be successful





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Conclusion

- The location of the base station is critical for the survivability and privacy of the network
- We present a receiver-location privacy solution capable of countering both passive and active attackers
- The protection mechanism introduce additional overhead and impacts on the delivery time but it includes two parameters to balance between usability and security
- Future work
  - Reduce the overhead caused by fake traffic
  - Protect the topology discovery process

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Thanks for your attention!

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Extra Slides

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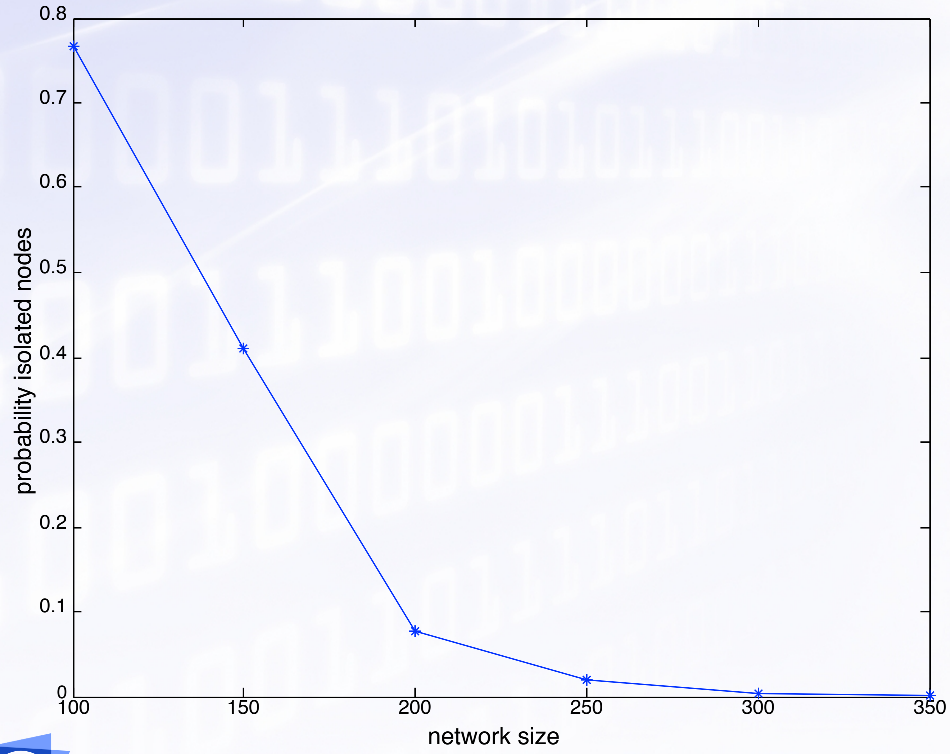
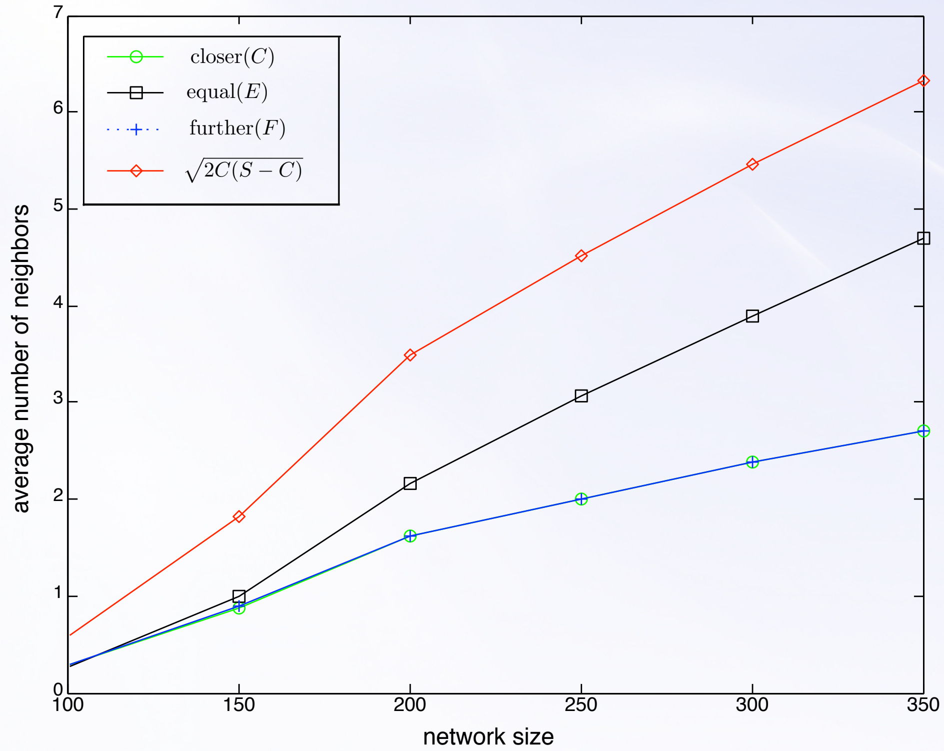
Analysis of Potential Limitations

- The topology of the network might negatively impact the convergence of real packets
  - Theorem: Real messages reach the base station if $F < \sqrt{2C(S-C)}$

- Validation on randomly deployed networks





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