A Hierarchical Network Architecture for Intelligent Manufacturing and Logistics

Kiriakos Georgouleas, R&D Engineer, Hellenic Aerospace Ind.
Kostas Kalaboukas, Singular Logic
Adrian Poblacion Hernadez, Universidad Politecnica de Madrid
Pedro Malo, UNINOVA

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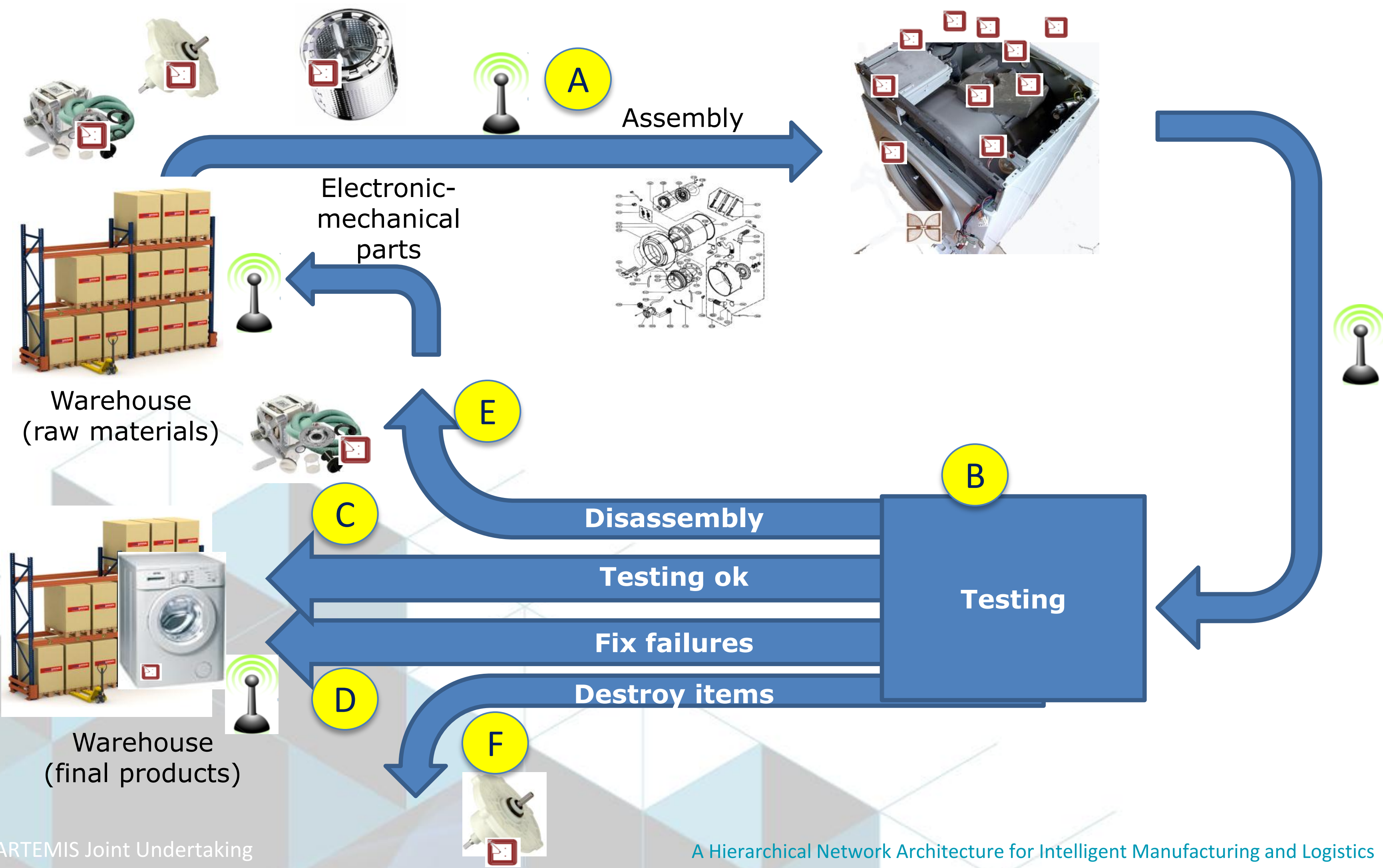
Overview

- Wireless Sensor Networks (WSNs) and smart tags in the fields of manufacturing and logistics
- Classification of smart objects and network architecture
- Geographic routing in WSNs
- Localization Techniques for indoor environments
- Trust schemes for WSNs

Introduction

- Key Functions of WSNs and Smart Tagging in Manufacturing and Logistics
  - Automatic Identification
  - Precise Localization
  - Sensing and Conditions Monitoring
  - Actuation
- WSNs advantages: Flexibility, self-organization, low-cost, rapid deployment, distributed processing capability, self-healing network operation

Introduction of Smart Objects in Manufacturing

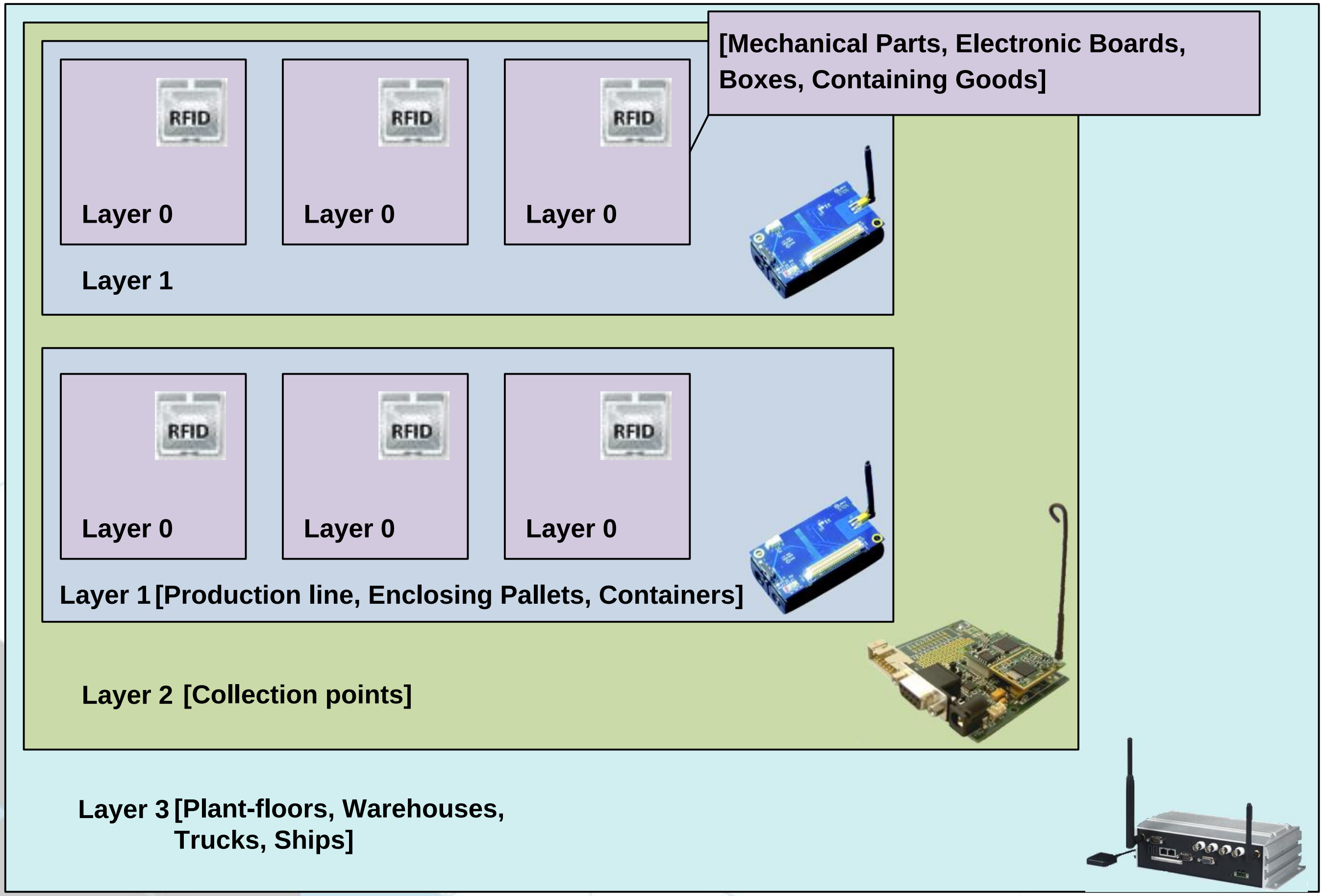


Introduction of Smart Objects in Logistics

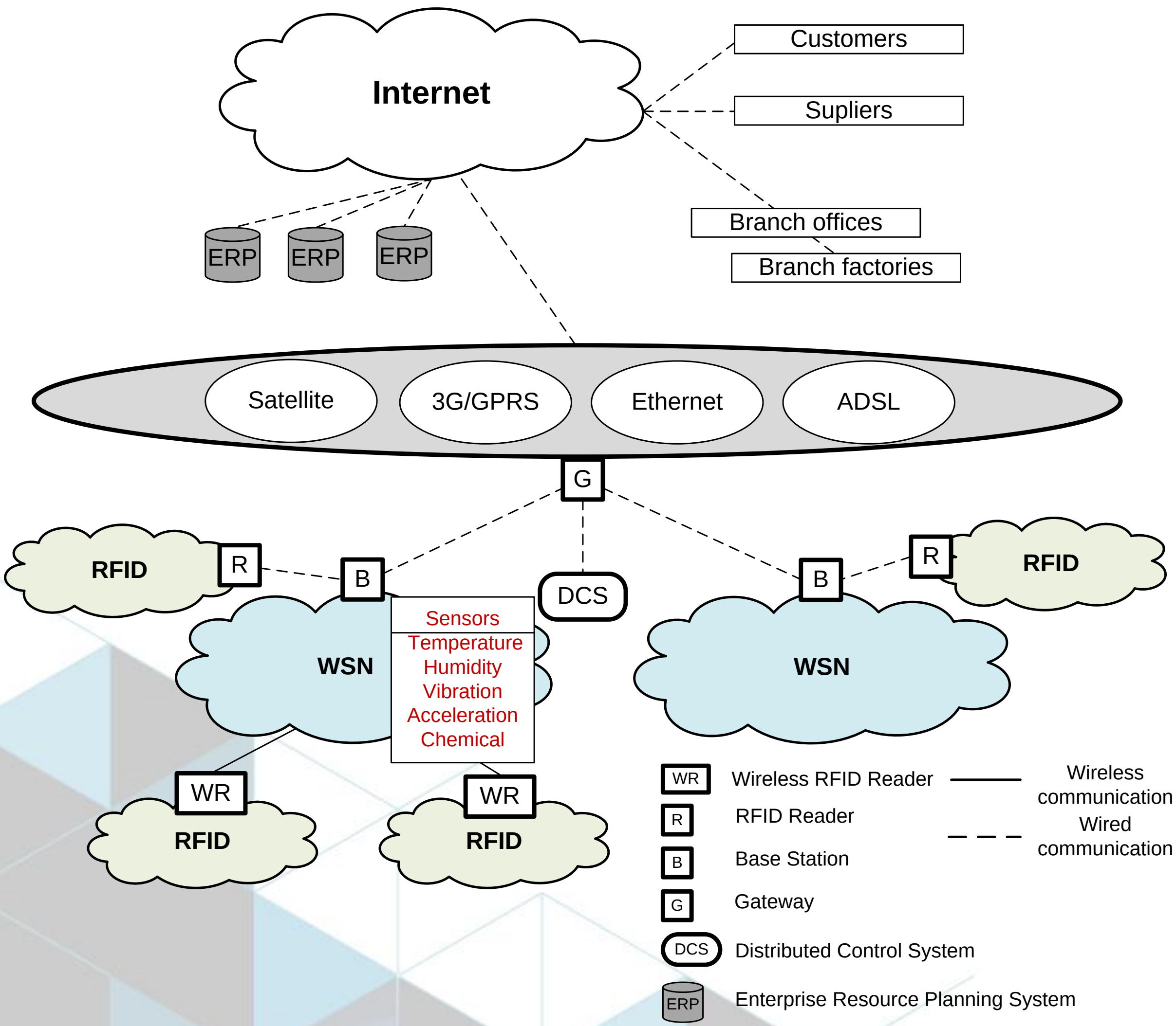
Network parameters for investigation in Intelligent Manufacturing and Logistics

1. Topology
2. Coverage area
3. Energy consumption
4. Mobility
5. Scalability
6. Interference
7. Location knowledge
8. Security and Trust

SIMPE 4-Layers Smart Objects Classification



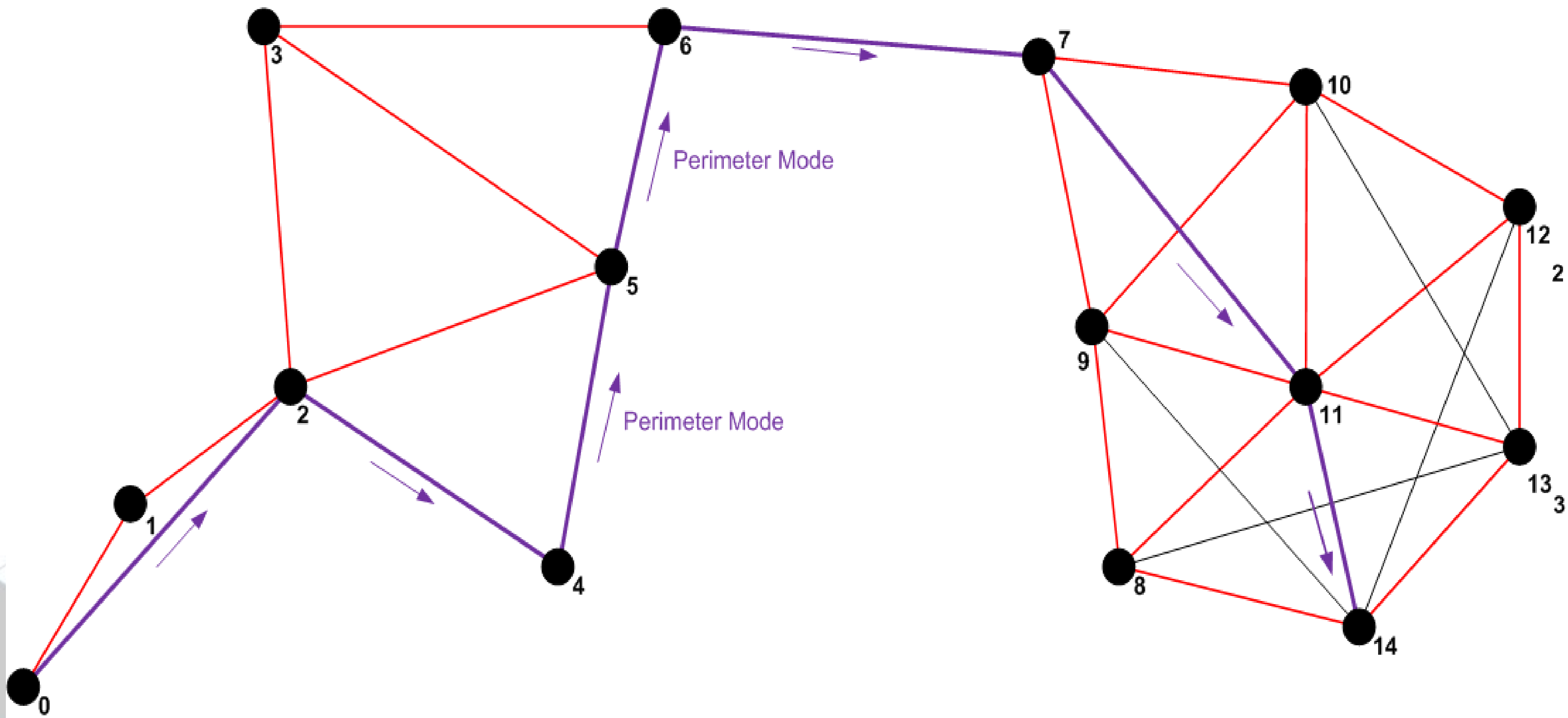
SIMPLE Network Architecture



Routing in WSNs

- Routing in Wireless Sensor Networks
  - Several solutions presented over the last two decades
  - Challenges: Constraint devices, low speed unstable and lossy links, energy consumption, very large scale, unattended operation in harsh environments
  - Solutions presented include:
    - Flooding and gossiping
    - MANET protocols (DSR, AODV, DYMO)
    - Cluster-based hierarchical routing
    - Geographic Routing
    - Self-organizing coordinate systems / Gradient routing

GPSR Routing Example Topology

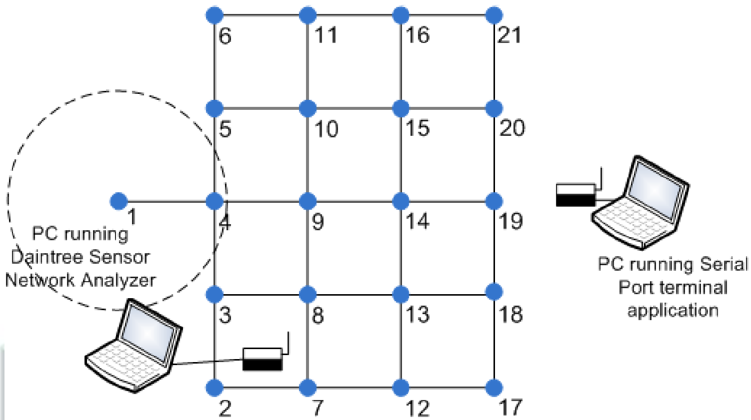


Routing from Node 0 -> Node 14

GPSR Routing advantages: Low algorithmic complexity, Scalability, Adaptability, Optimality, Guaranteed delivery

Testbed Evaluation of Geographic Routing

- Testbed composition: 21 IEEE 802.15.4-compliant Memsic IRIS nodes with pre-programmed position coordinates
- TinyOS 2.x Operating System



Operation of multihop GPSR based routing validated with average PRR measured 97.2% for constant traffic every 10 sec

Geographic routing improvement: combine distance with link quality

- Received Signal Strength Indication (RSSI)
- Link Quality Indicator (LQI)
- Expected Transmission Count (ETX)

Localization Techniques using WSNs in Indoor Environments

- Advantages of localization in WSN:
  - Low cost
  - Low energy
  - Works in indoor environments
- Localization of network nodes requires the existence of:
  - Nodes whose position is perfectly known (anchor nodes - AN)
  - Nodes whose position is unknown (mobile nodes - MN), but can be estimated with the help of the ANs
- Two distance-related measurements can be obtained by sensor nodes:
  - Received signal strength (RSS)
    - Most standard motes provide RSSI. This is a coarsely quantized value of RSS, not intended for accurate ranging
    - Frequency selective fading (specially in indoor environments) severely impairs RSS measurements
  - Signal time-of-arrival (TOA)
    - Not supported by conventional (IEEE 802.15.4) motes, only available in devices that conform to the IEEE 802.15.4a PHY

Testing Range-based Localization using TOA

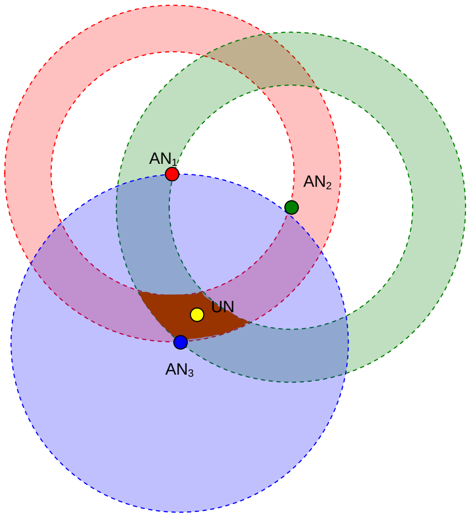
- Motes: NanoLOC from Hanback
- IEEE 802.15.4a modified: 80 MHz bandwith instead of UWB (>500 MHz)
- Tests: Room of 9 m^2 with 5 ANs with an average separation between them of 3 m.
- The position of the MN was estimated using trilateration in 52 different locations
- Considering the root mean square error:

$$RMSE = \sqrt{E((X_{estimated} - X_{real})^2)} = \sqrt{\frac{\sum_{i=0}^{n}(x_{i,est} - x_{i,real})^2}{n}}$$

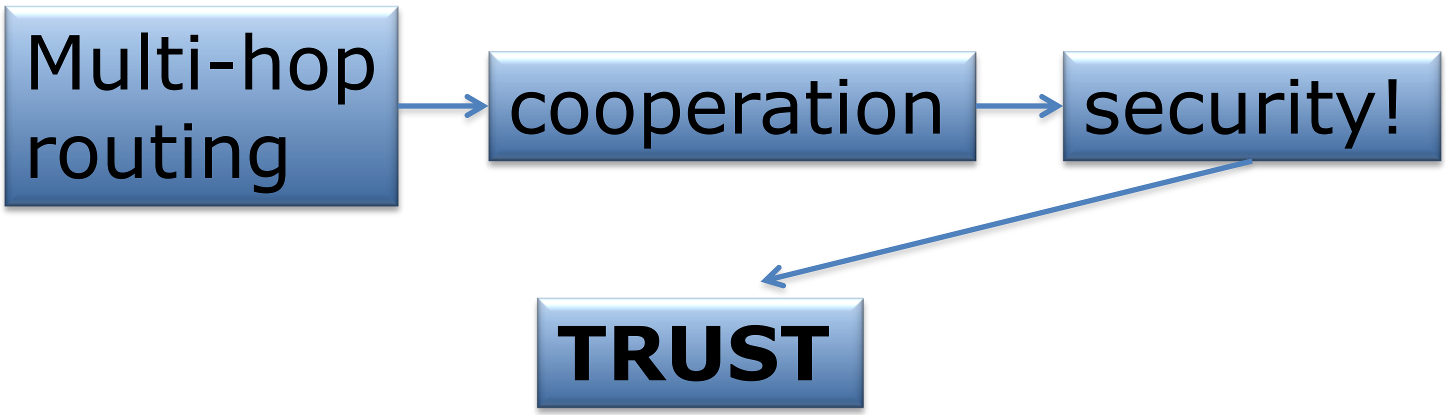
- Experiments resulted in RMSE=37cm which is satisfactorily accurate

Testing Range Free Localization using RSSI

- Motes: Iris from Crossbow
- IEEE 802.15.4 standard: supported by most motes
- Tests: 7 ANs deployed in a room of 9 m^2 divided in a grid with cells of 30 cm^2
- The MN was placed in 46 different regions among the ANs. Position estimated using a ROCRSSI algorithm
- RMSE depends directly on distances between ANs. The RMSE obtained is 47 cm, about one half of the minimum separation



Trust and Security in WSNs



- Nodes monitor the behavior of their neighbors
- Nodes establish trust relations with their neighbors
- Nodes avoid selecting malicious neighbors as next-hop

SIMPLE Trust Model

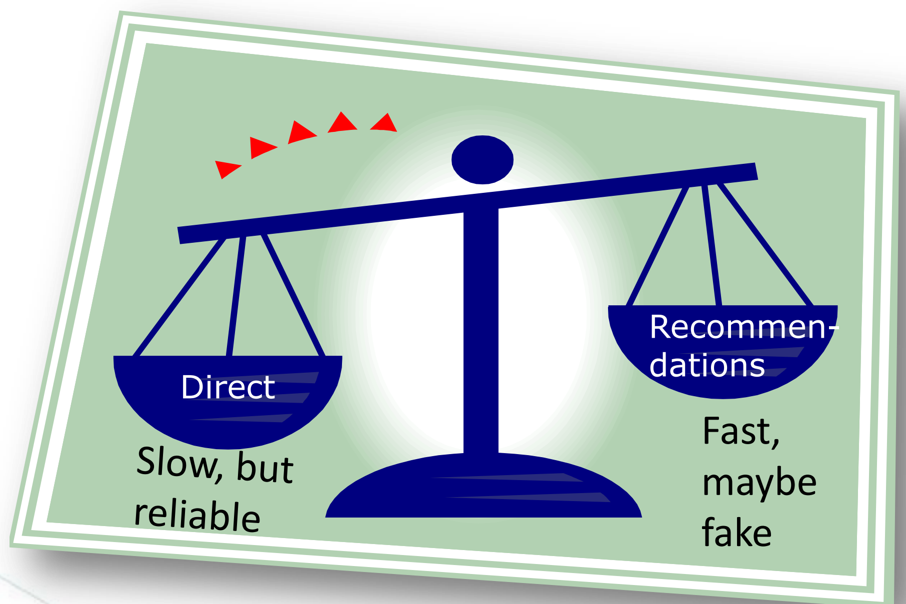
Trust

Direct:
node's personal opinion

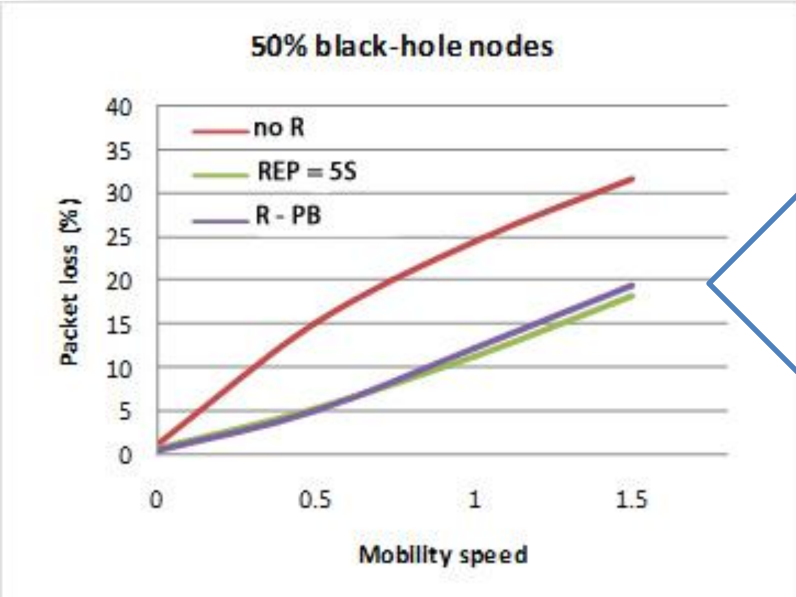
based on

Trust Metrics:
- Packet forwarding
- Packet Precision
- Network layer ACK

Recommendations:
other nodes' opinions
(both positive and negative)

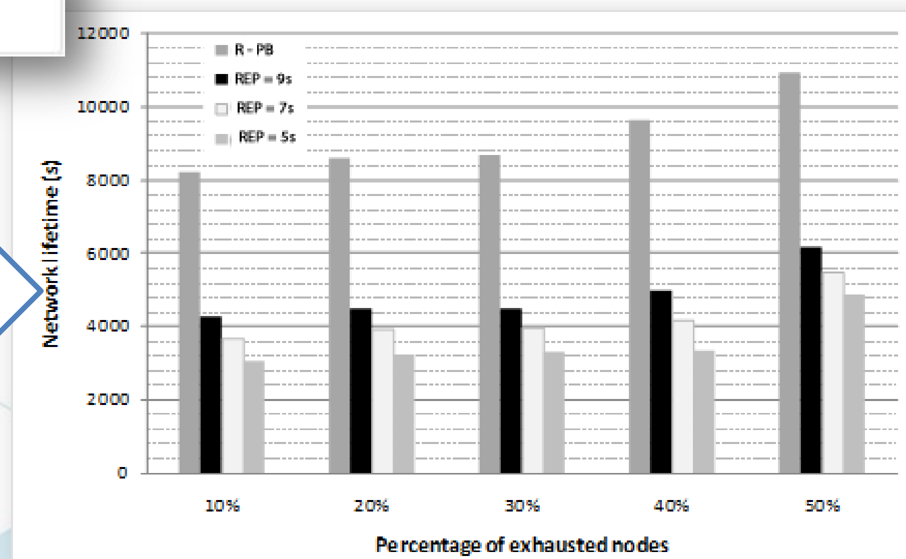


SIMPLE Trust Simulation Results



- network of 100 mobile nodes
- initially placed on a grid every 100 distance units
- 50% randomly distributed black hole nodes
- no recommendations
- recommendations in dedicated messages every 5sec
- recommendations piggybacked in beacons

Network lifetime vs tolerable percentage of the exhausted nodes in an active network for different recommendation exchange configurations, (REP: recommendation exchange period, PB: piggybacking)



Conclusions

- SIMPLE routing scheme advantages: improved performance, scalability and energy consumption, localization capability, inherently trusted and secure operation
- SIMPLE innovative technologies will be realized and tested at Gorenje manufacturing plant for white goods production and Selex SI facilities for warehouse management and logistics use case
- Integration of WSNs and RFIDs with existing infrastructure networks (IP, cellular networks) will provide new services like online transportation monitoring at item level and asset tracking in production lines

Thank you for your attention!

Kiriakos Georgouleas
Georgouleas.Kiriakos@haicorp.com

simple

www.simple-artemis.eu

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