APR: A New Ad Hoc Routing Protocol for Wireless Sensor Networks

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  - Review on Ad Hoc Routing Protocols
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Motivation

WSNs for new indoor-fire emergency and response systems: see http://www.firegrid.org

- Large-scale and dense distribution of sensors
  - 10^3 – 10^6 sensors per building expected
- Unpredictable events
  - Sensor failures, fire ignition time, scale and progress speed etc.
- Redeployment and destruction
  - can be frequent
- Power
  - limited supply, batteries
- High traffic load
  - packet delay and loss can be significant

Review: Wireless Sensor Networks

Performance Issues

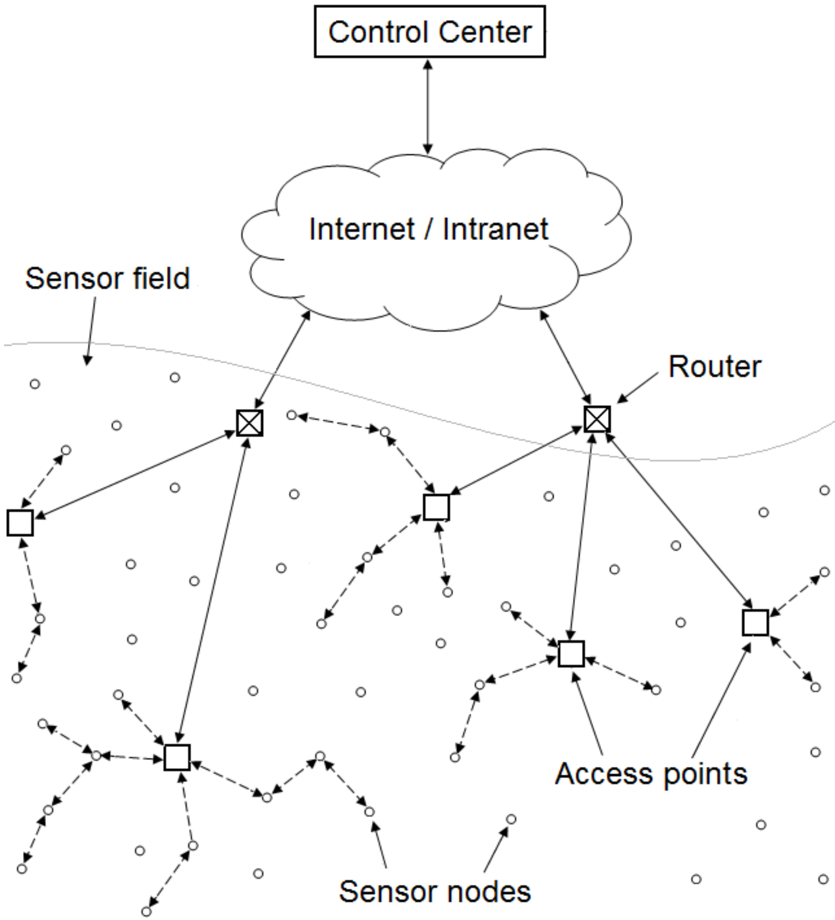
- Physical Layer
  - Coding and Modulation, e.g. QAM, PSK
  - Power reduction due to fading and attenuation can significantly increase packet loss rate
- Link Layer
  - Media Access Control, e.g. 802.11
  - Transmission can fail due to channel collision among neighbours, interference from background noise or remote nodes
- Network Layer
  - Routing for destinations, e.g. HSR, AODV
  - Node configuration task and routing traffic can be overwhelming

Review: Wireless Sensor Networks

Review of Ad Hoc Routing Protocols

- Index-driven
  - Examples: Hierarchical state routing (HSR), Geographic Routing and many variants.
  - Theoretically support large-scale networks
  - Configuration is difficult if node population is high
  - Failure of key nodes can result in system failure
- Distance-vector-based
  - Examples: Destination-Sequence Distance-Vector (DSDV), Ad hoc On-demand Distant Vector (AODV) and many variants
  - Self-organising and thus easy to deploy / redeploy
  - Can recover from node failures
  - Routing traffic limits network scalability

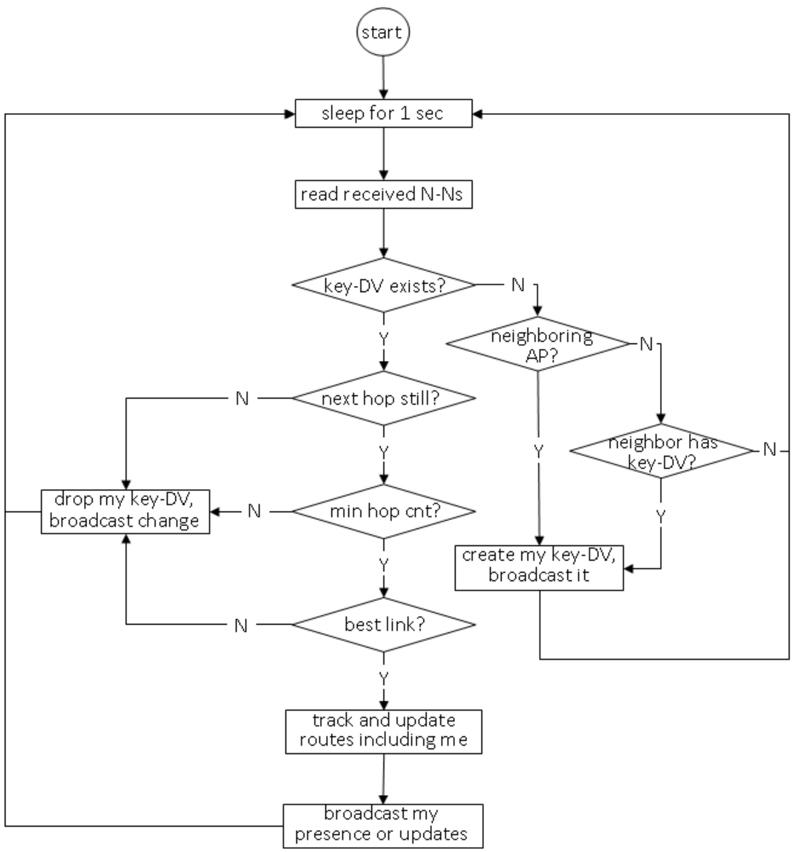
Access Point Routing



Strategy:
- Wired network backbone
- Multiple access points
- Wireless sensor (mesh) networks

Targets:
- Self-organising in deployment
- High responsiveness upon unpredictable events
- Agilent route discovery and recovery against destructions
- Balancing traffic load to sensors

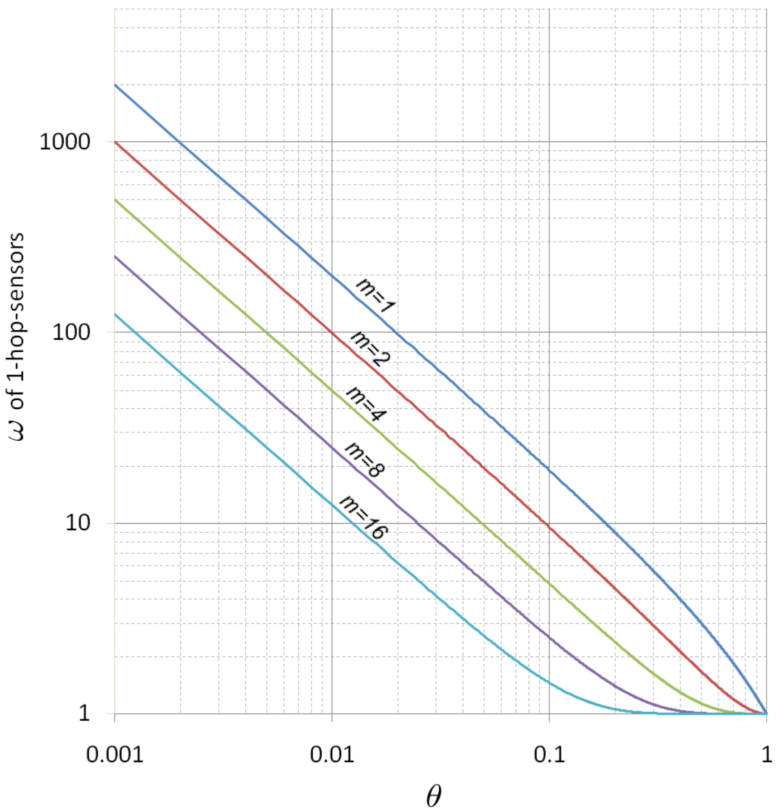
Access Point Routing



An APR Variance:

- Locate closest Access Point (AP)
- Establish key-route with minimum-hop-count to AP
- Broadcast key-route with Neighbour-Notifications (N-Ns)
- Optimise key-route with best-link-quality as detected
- Drop invalid or non-optimal routes (e.g., neighbour timeout, shorter path discovered)

Access Point Routing



Analysis:

Normalised Communication Load, $\omega = (2\mu+\lambda)/\lambda$, on 1-hop-sensors:

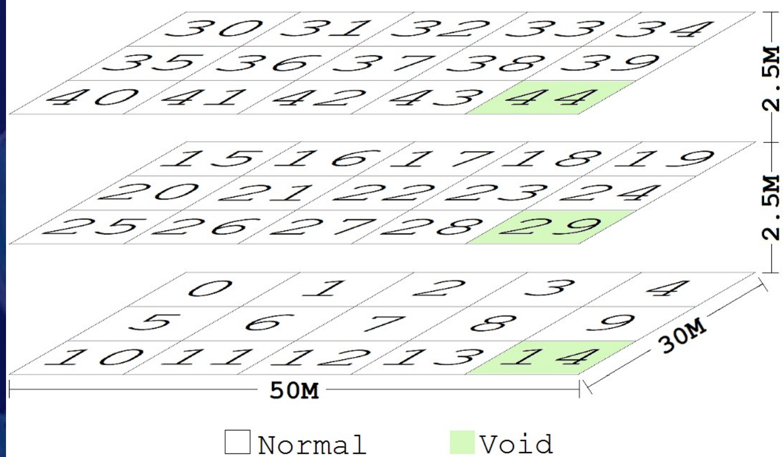
$$\omega(m) = [1 + (1 - \theta)^m] / [1 - (1 - \theta)^m]$$

where λ is generated traffic, μ is relayed traffic, m is the number of access points, θ is the coverage percentage of the entire sensor field by a single sensor.

When $\theta >> 1$ (large networks):

$\omega(m) \approx [\omega(1)+1]/m - 1$

Simulation

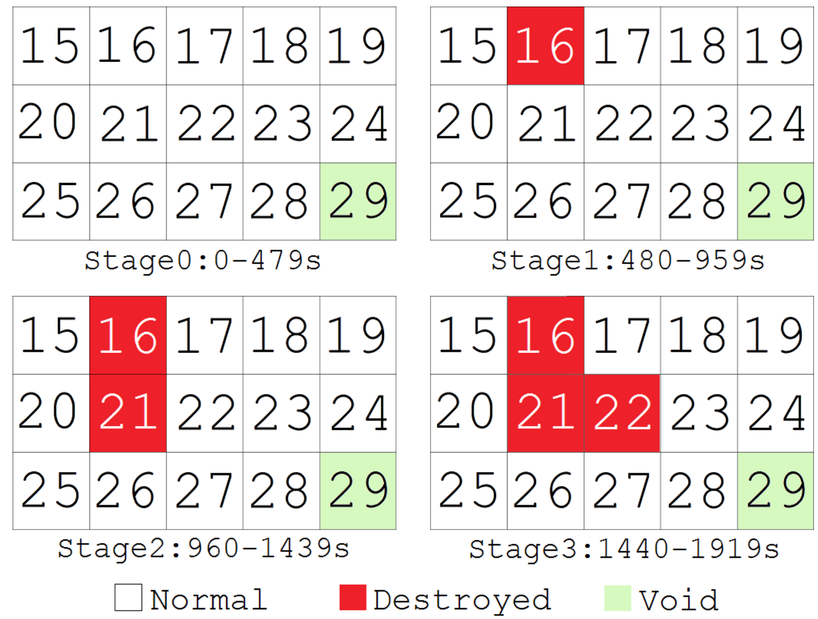


Overview

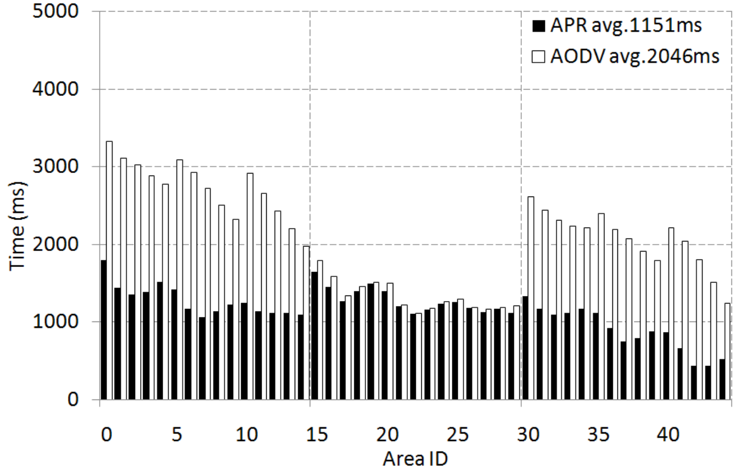
- 3 floors, 45 areas, 900 sensors
- Partitioning
  - chip-board separates neighbouring areas (-13.5dB)
  - concrete ceiling between floors (-60dB)
  - Stairway in Area 14, 29 and 44
- Communication Settings
  - Modulation: QAM
  - 40 dB for initial, 9.52 dB for neighbour threshold
  - 802.11, RTS/CTS collision avoidance
  - 0.5Mbps if contention-free
  - Packet size: 1250 octets
- Access points
  - APR: area 7, 22, 37
  - AODV: area 22

Simulation: Scenario I

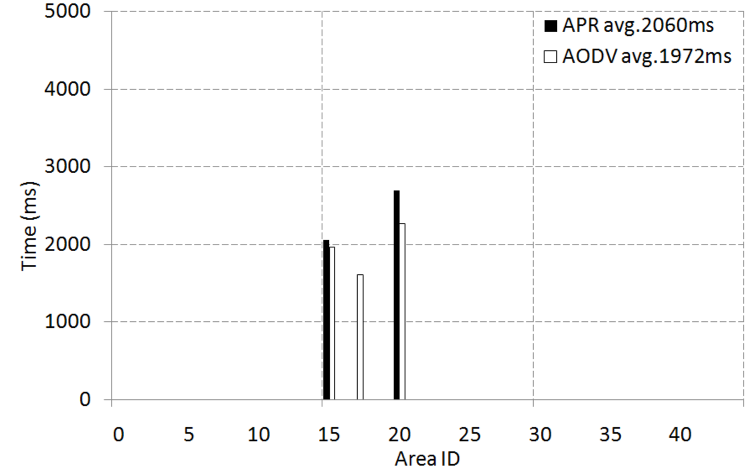
- Stage 0 (0 - 479 s): No fire
- Stage 1 (480 - 959 s): Fire ignition in Area 16
- Stage 2 (960 - 1439 s): Fire progresses to Area 21
- Stage 3 (1440 - 1919 s): Fire progresses to Area 22



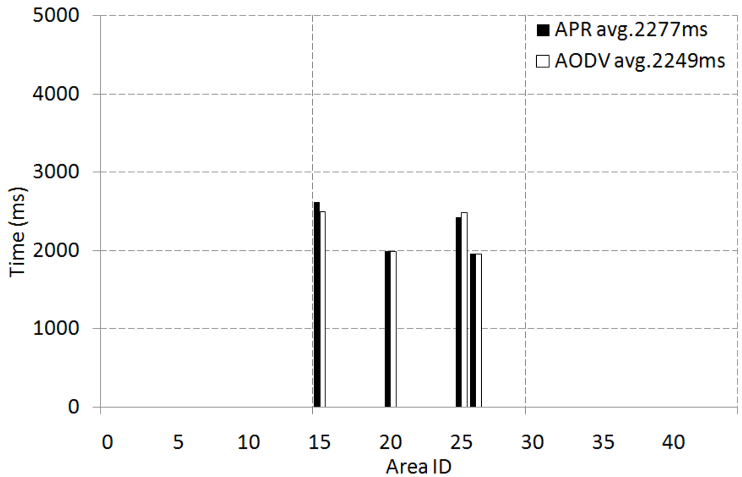
Route Establishment and Recovery Time



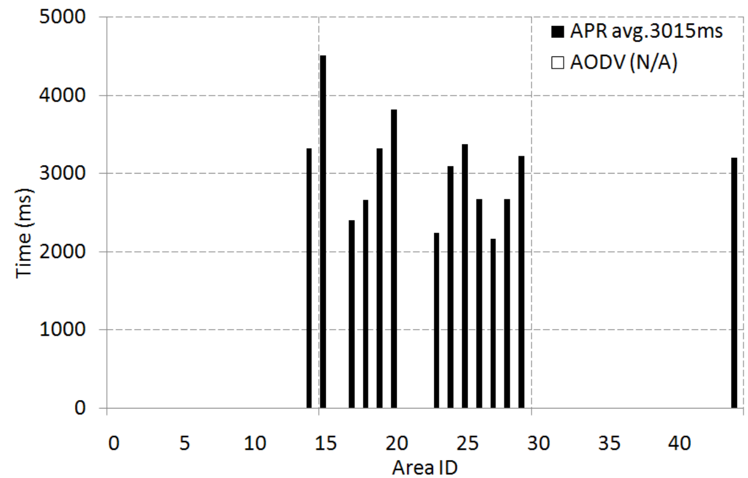
Stage 0



Stage 1

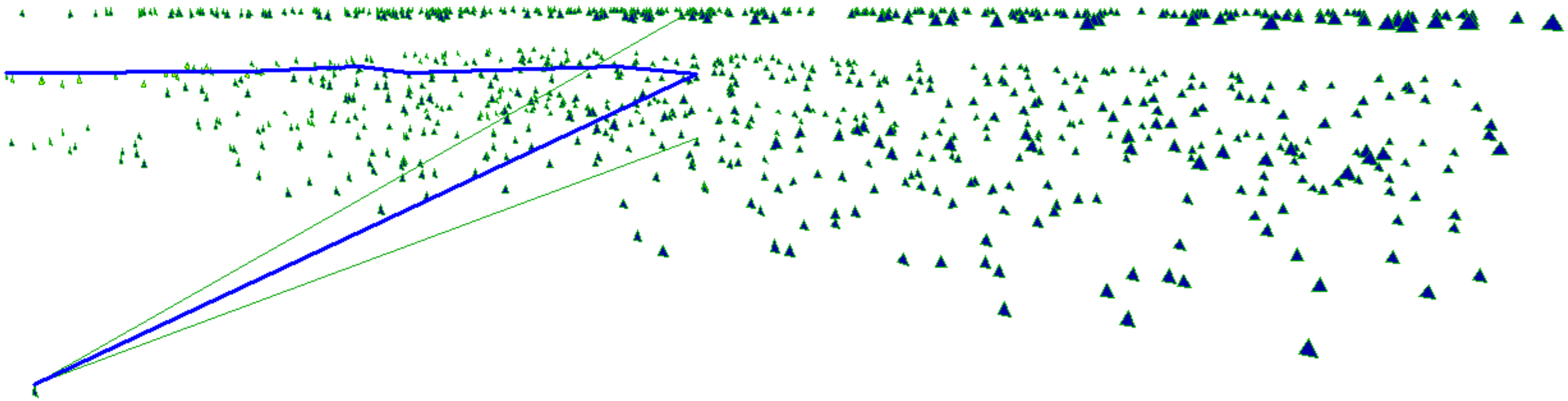


Stage 2

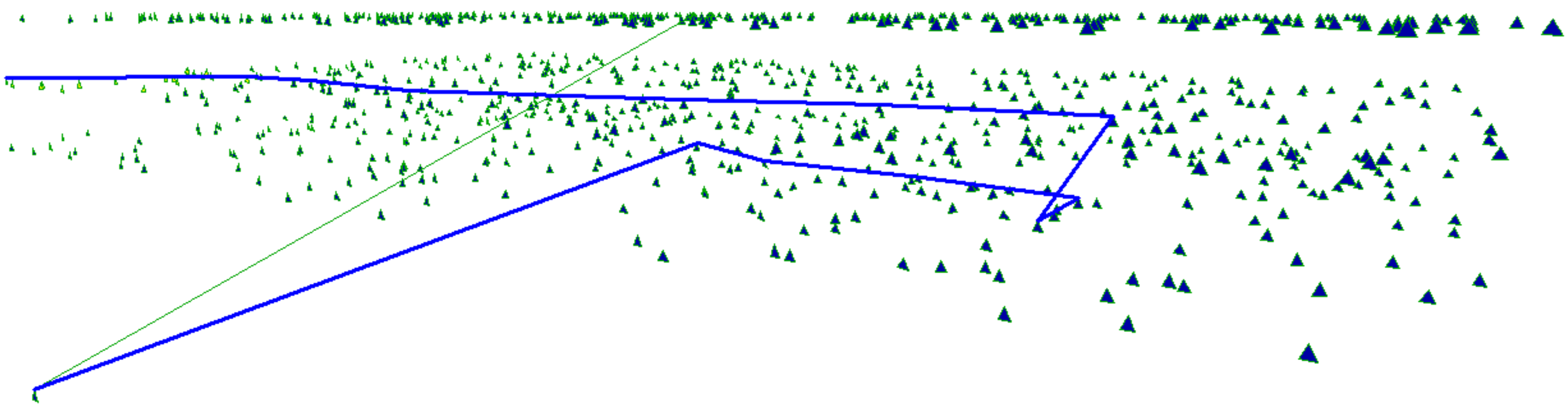


Stage 3

Screenshots

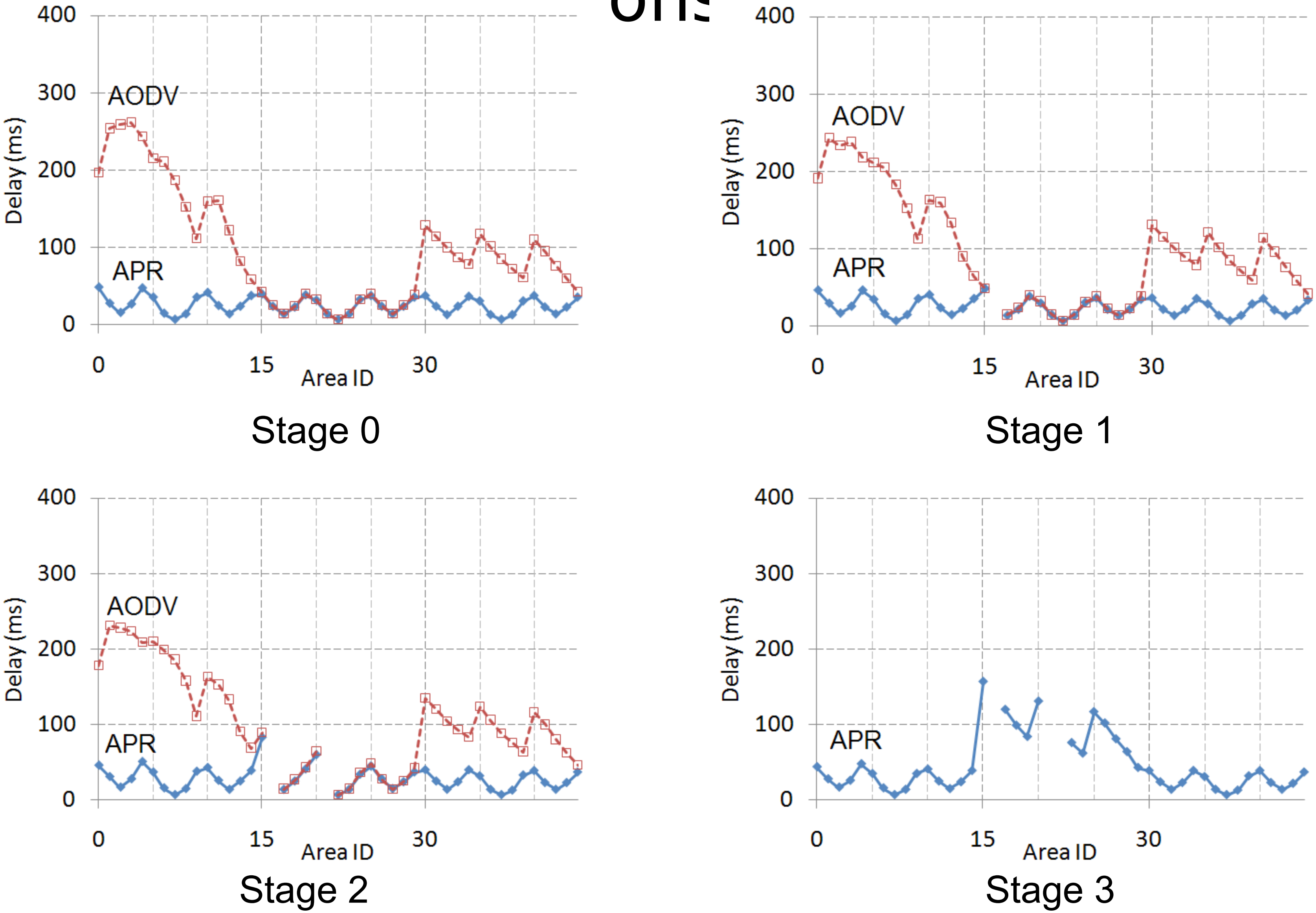


APR in Stage 2: before loss of Area 22

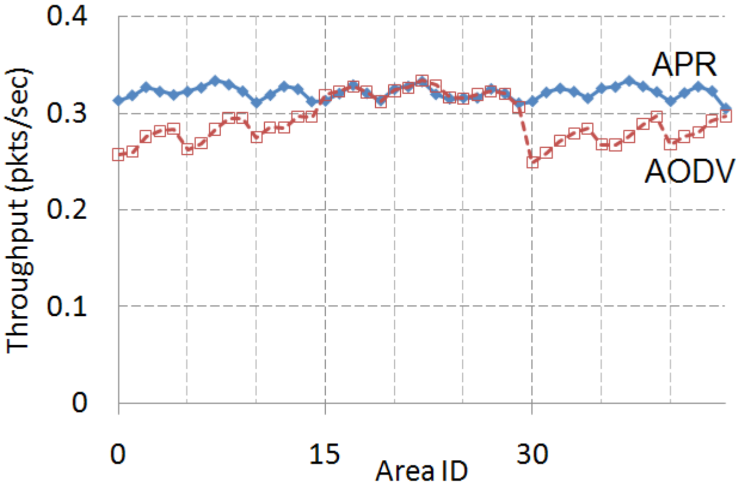


ARP in Stage 3: after loss of Area 22, route recovery through the stairways

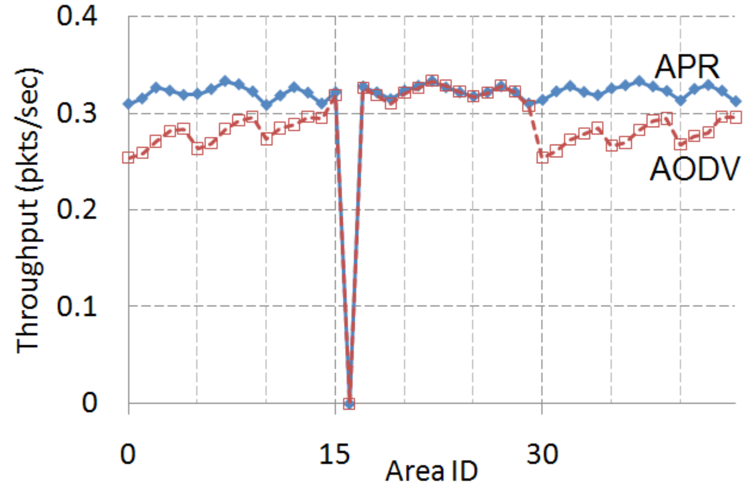
Packet Delay Distributions



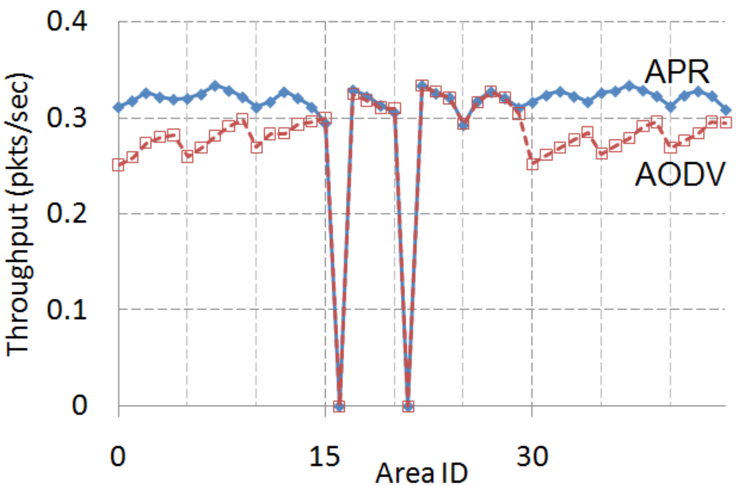
Area Throughput Distributions



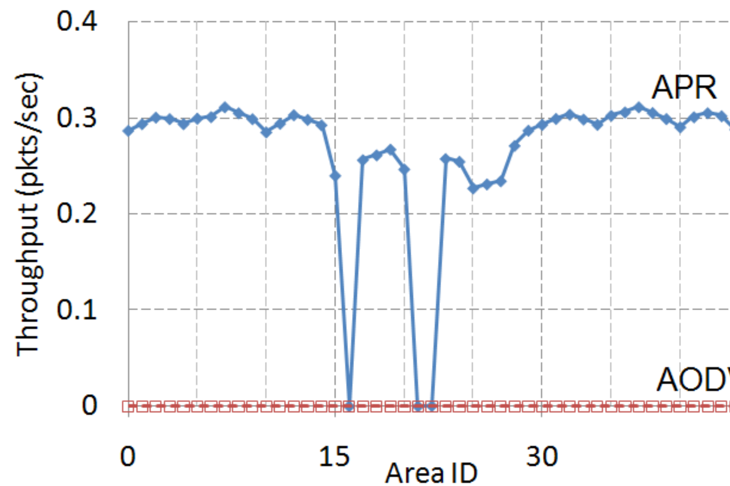
Stage 0



Stage 1

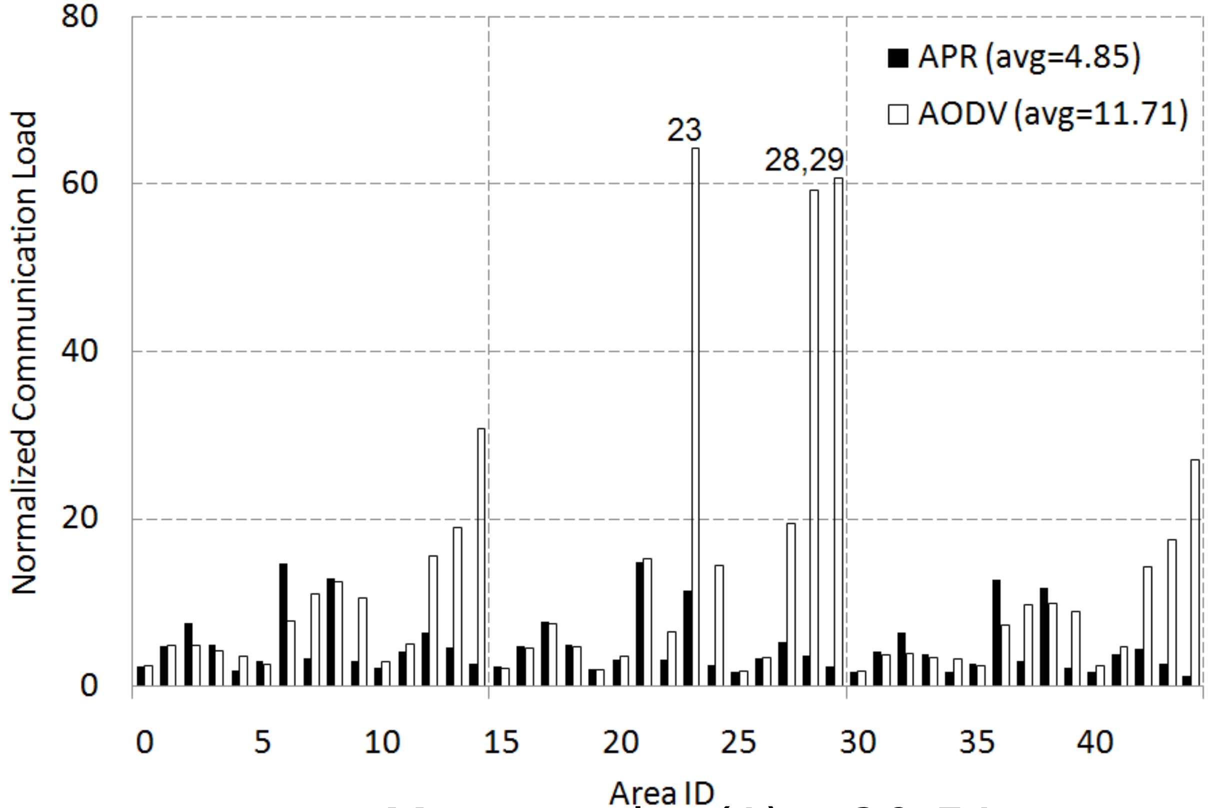


Stage 2



Stage 3

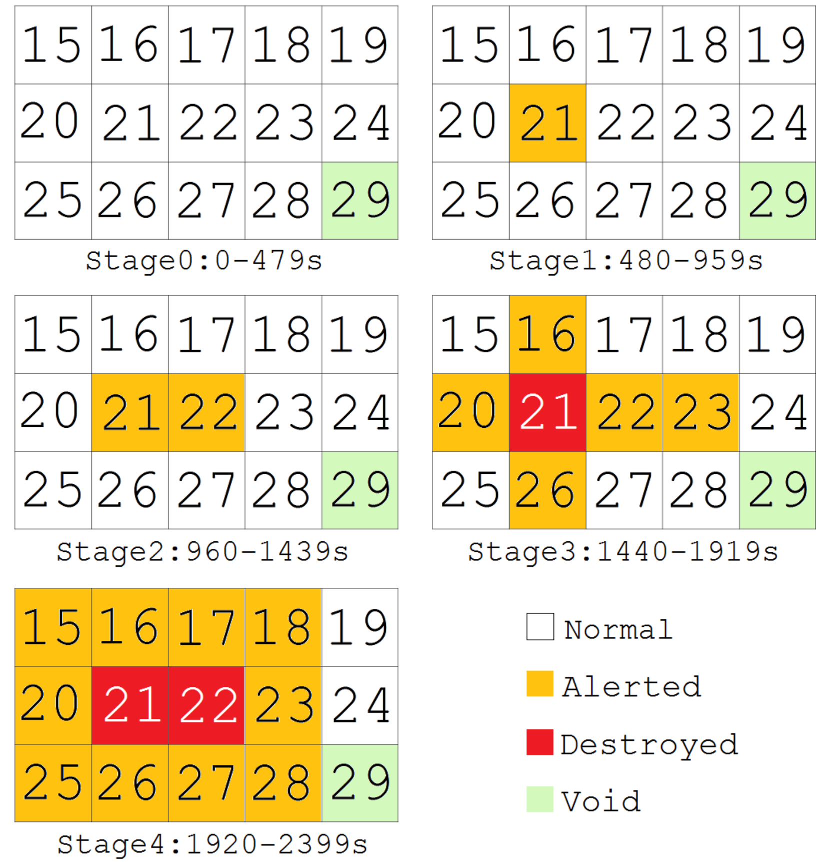
Normalised Communication Load



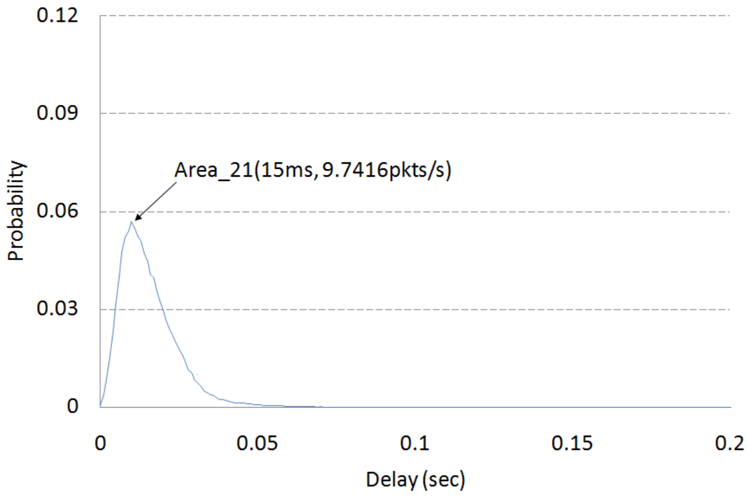
Measured *ω(1) =20.51*
Analytical *ω(3)* = 6.17
Simulation *ω(3)* = 6.55
Deviation caused by packet losses

Simulation: Scenario II

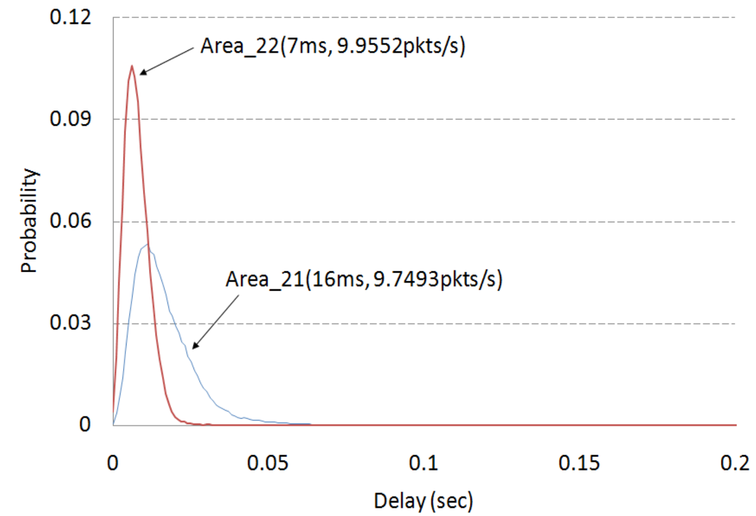
- Stage 0 (0 - 479 s): All sensors are in the Normal state
- Stage 1 (480 - 959 s): Abnormalities sensed in Area 21
- Stage 2 (960 - 1439 s): Abnormalities sensed in Area 22
- Stage 3 (1440 - 1919 s): Fire destroys Area 21; alerts in Area 16, 20, 26 and 23
- Stage 4 (1920 - 2399 s): Fire destroys Area 22; alerts in Area 15, 17, 18, 25, 27 and 28



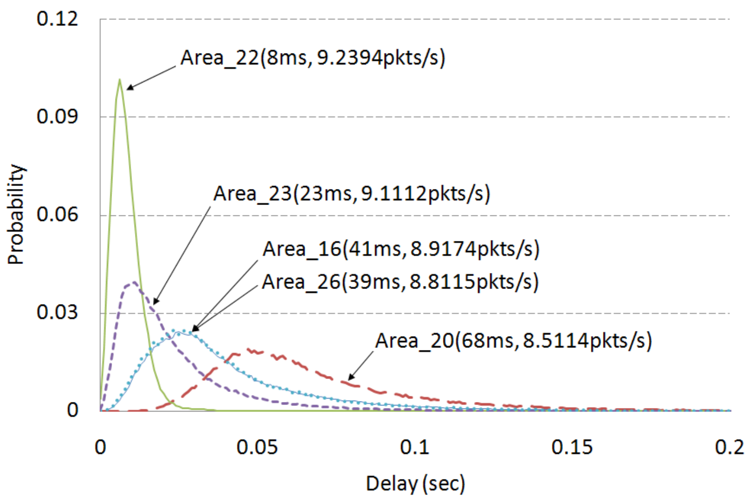
Packet Delay PDF in Alerted Areas



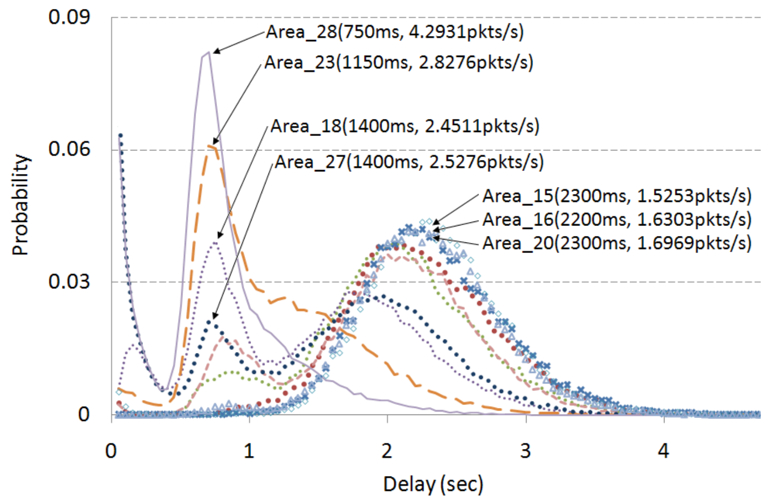
Stage 1



Stage 2



Stage 3

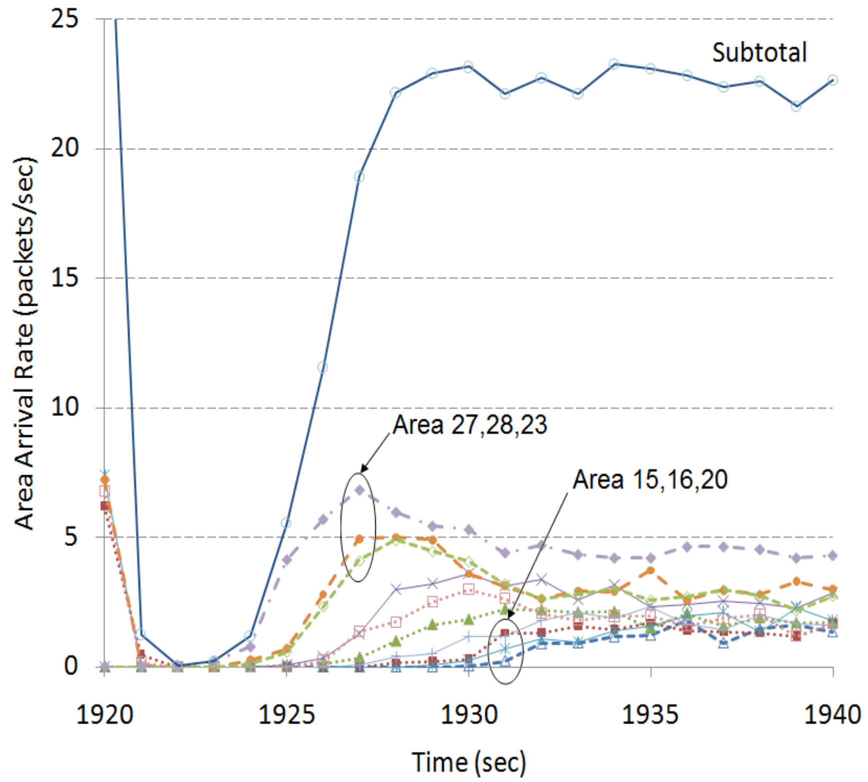


Stage 4

Arrival Rate at Control Centre (1st 20 sec in Stage4)

- Packet delay PDFs of AODV are similar to APR in Stage 1, 2 and 3, but AODV fails in Stage 4

- APR can recover after the loss of Area 22. The recovery speed of areas differ due to geographical distance



Conclusion

APR outperforms AODV as measured in terms of:

- Route establishment and recovery time
- Traffic load
- Packet delay
- Per sensor throughput
- Robustness of the system to destruction of key nodes in the network