Adaptive Wireless Sensor Networks

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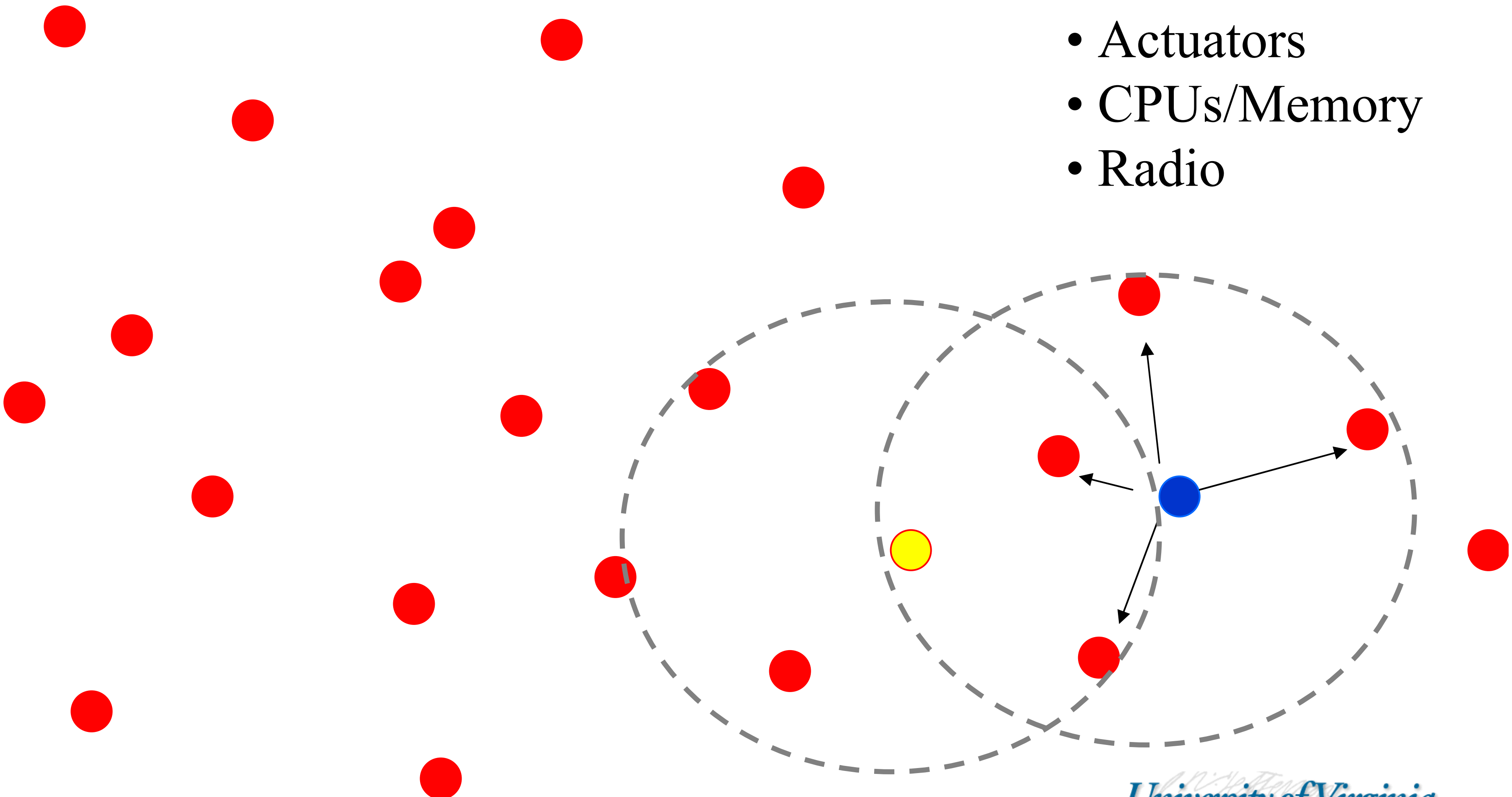
Outline

- Characteristics of WSN
  - Middleware services *act as* the OS
- Next Generation RTS
  - An application (built and demonstrated a WSN)
  - Stress the need for adaptation
- Adaptation Using Feedback Controllers
  - Routing
  - Packet Aggregation
- Summary

Wireless Sensor Networks

- Sensors
- Actuators
- CPUs/Memory
- Radio



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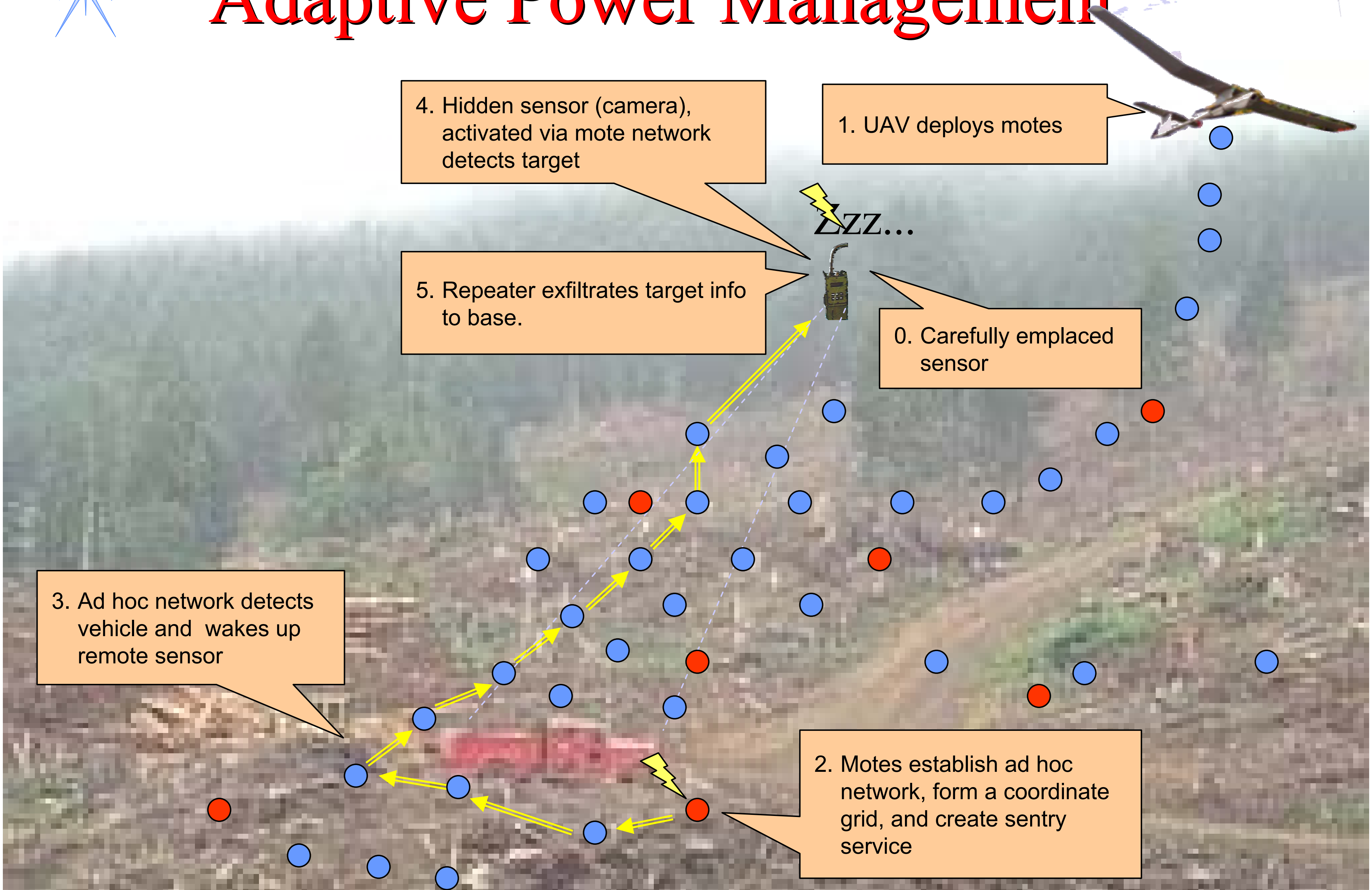
Characteristics of WSNs

- Self-configuring (self-*)
- Dynamic topology changes
- Unattended operation
- High degree of faults, lost messages, etc.
- Limited resources (especially power)
  - 4 MHz cpu; 128 KB memory; 40 Kbps
- Operate in (un) or limited controlled environments
- Operate in real-time environment with real-time constraints
- A new real-time system type!

"Adaptive Power Management"



Experimental Setup

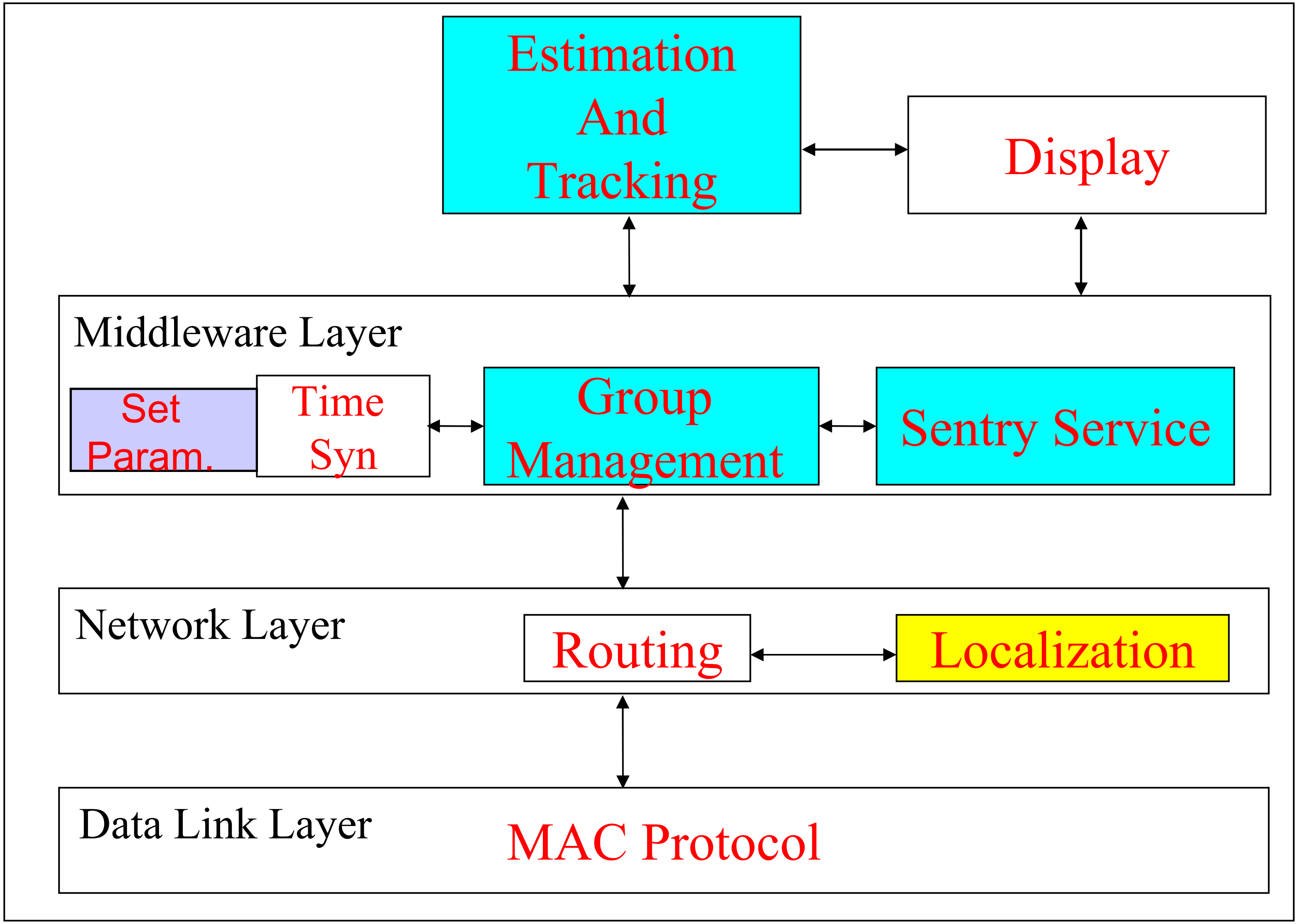
– Deployed in outdoor swampy area

- Placed by hand
- 70 Berkeley motes (MICA IIs)
- Spread across 300 feet
- Laptop that emulated SOCOM relay
- 2 video cameras that emulated SOCOM devices
- Actual remote (still) camera activated – ½ mile away
- Display

Goals

- Power management (extend the lifetime of the system)
  - Adapt to current power levels and alive nodes
- Real-Time Tracking
  - Adapt to speeds
  - *Adapt to false alarm rates*
- Modify functionality of the system

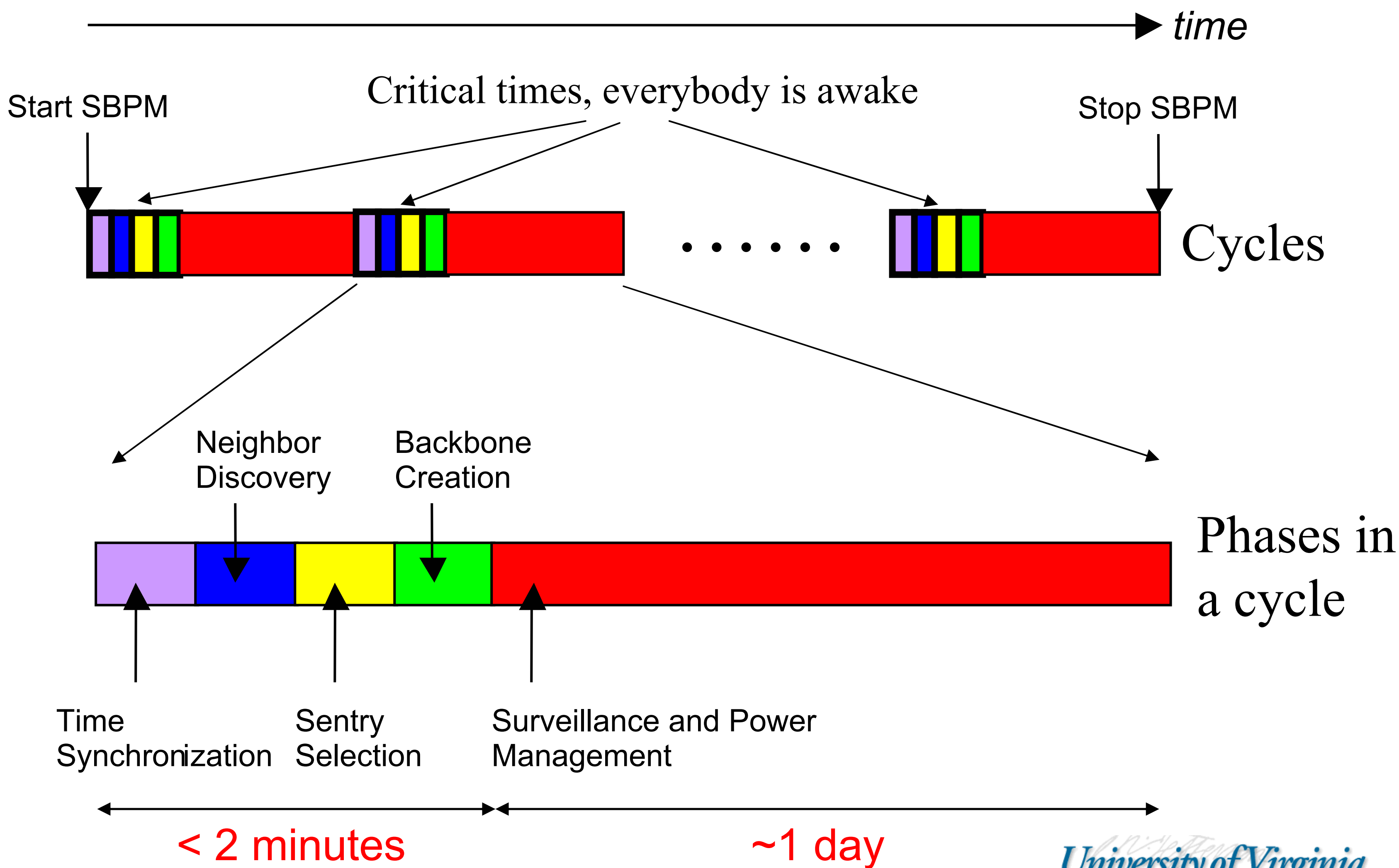
Protocols Implemented



Demo Scenario

- Phase I - Initialization
  - clock synchronization and system parameter settings (adaptive)
    - (sensor and false alarm thresholds; size of forward area; etc.)
  - location discovery *(used fixed values – replaced by location service)*
  - neighbor discovery
  - sentry selection (adaptive)
    - reliability of route to relays/base stations
  - backbone creation
  - backbone commit
  - power management (adaptive)
    - sleep/wakeup cycles; rotation period
  - report status (awake, sentry, sleep)

SBPM Cycles and Phases



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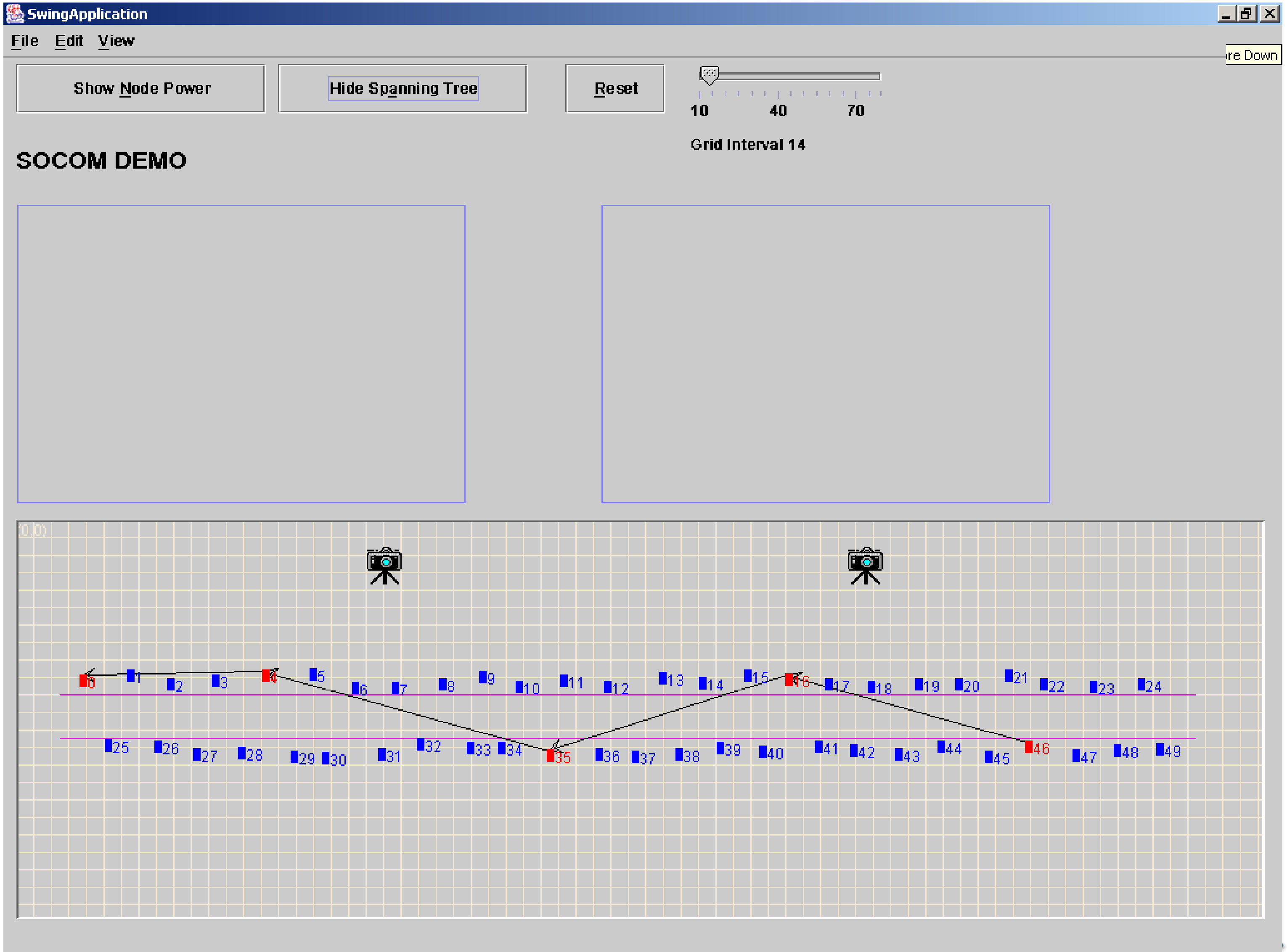
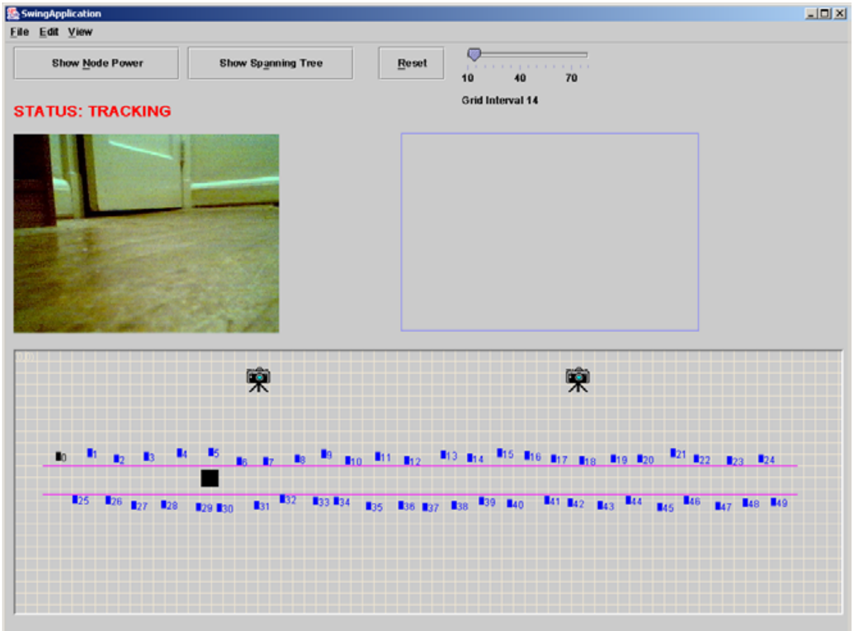
Initialization/Spanning Tree

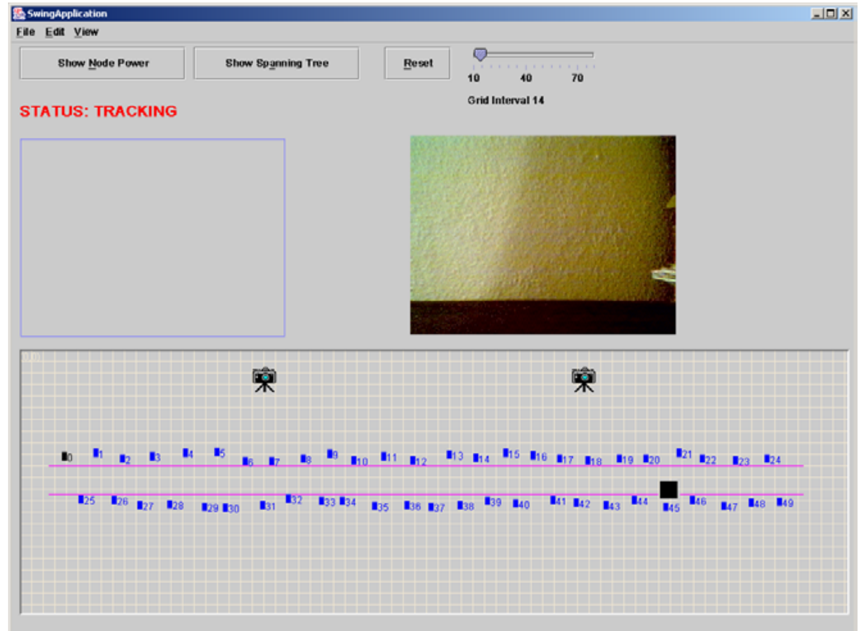


Demo Scenario

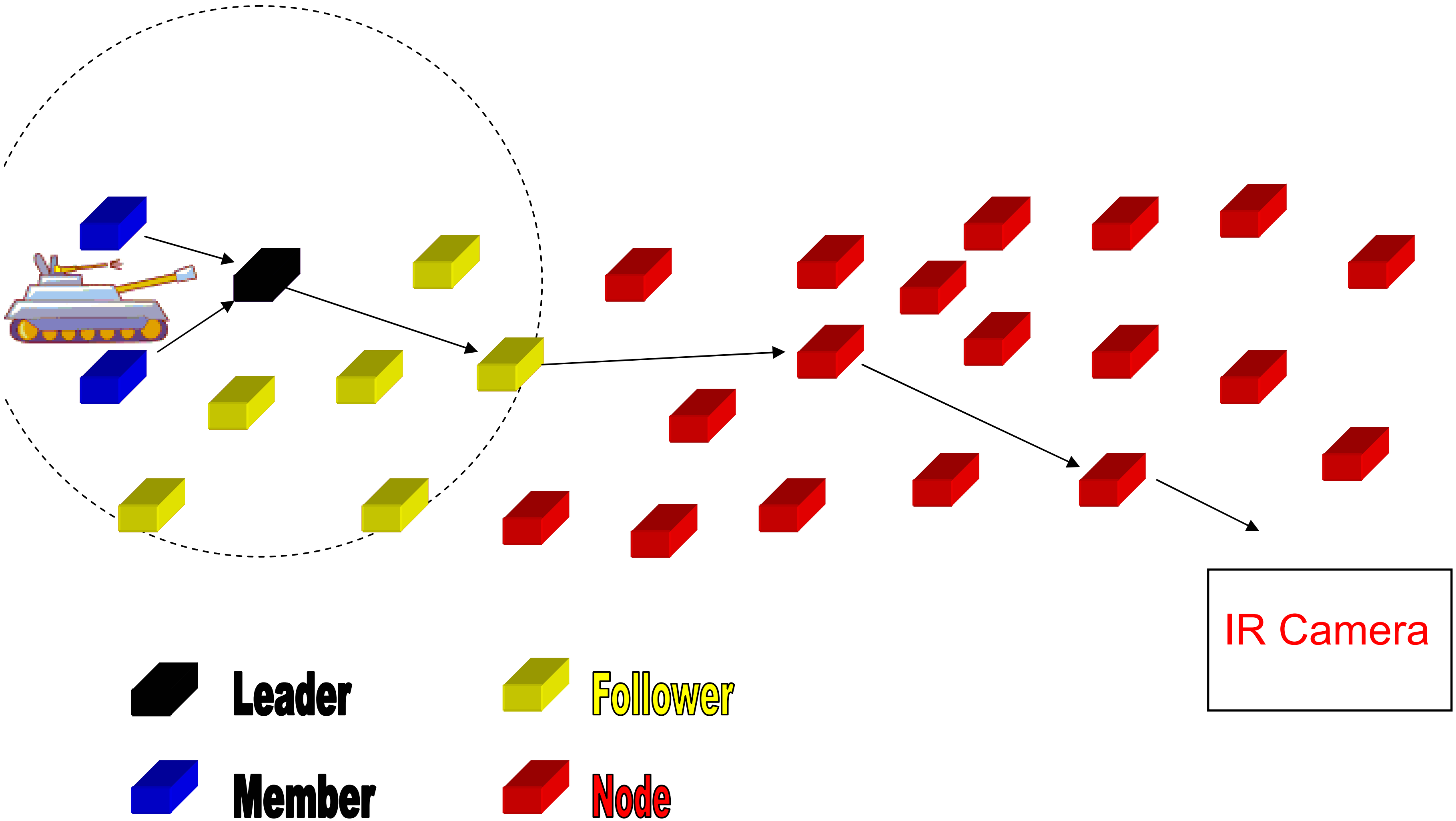
- Phase II - Detect and Track Entity
  - Vehicle enters mote field
  - Wake up first video camera
  - Wake up remote camera (1/2 mile away)
  - Tracking
    - confidence level (adaptive) of track shown
    - (forwarding area is function of speed)
  - As vehicle moves out of range
    - turn on second camera and shut down the first one

Waking Up -Tracking

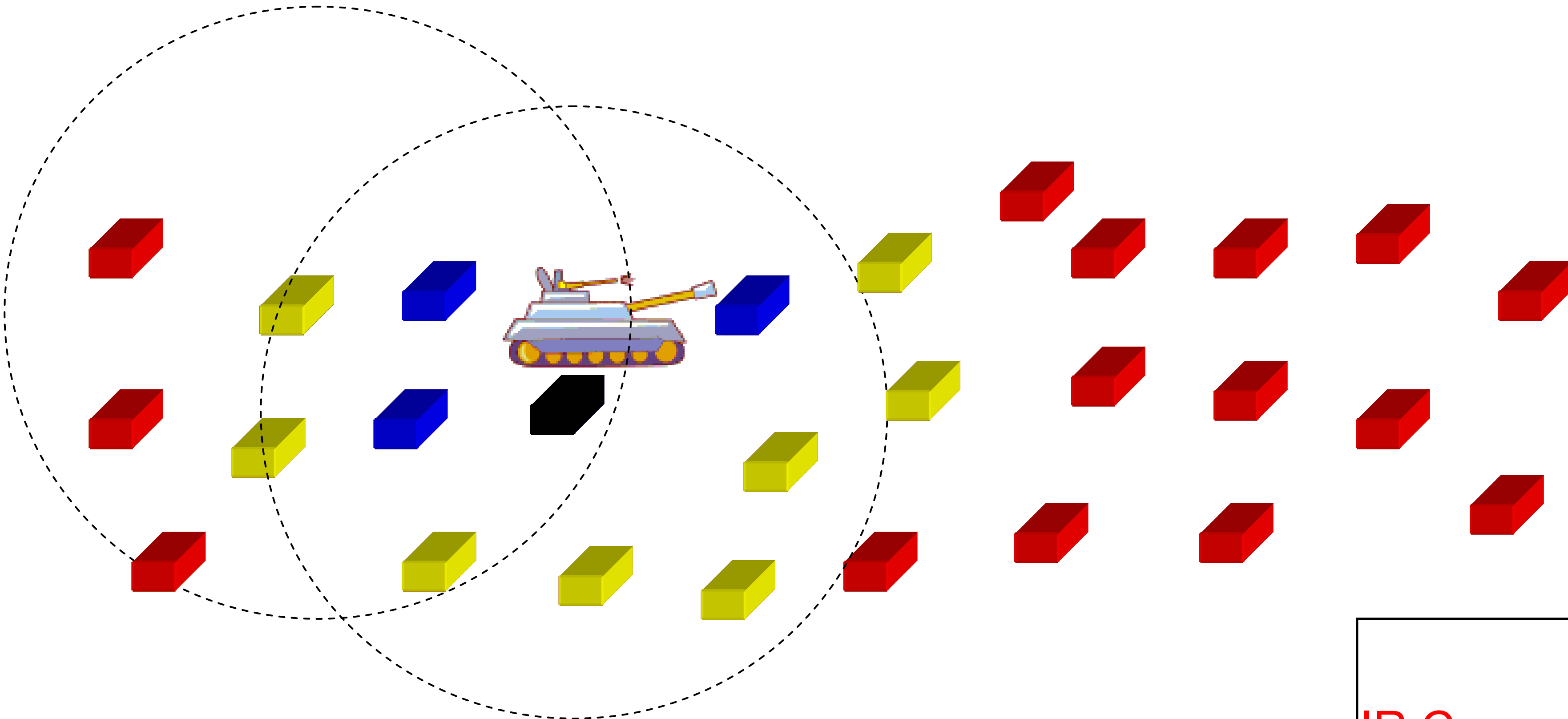




Group Management



Tracking



Adaptive – adjust size of follower area

IR Camera

Demo Scenario

- Phase III – Don’t Detect Person
  - Person walks through the area
  - Original goal
    - detect vehicles so do not detect this person
  - Send vehicle back through the area
    - detect and turn on cameras

Demo Scenario

- Phase IV - Sentry Rotation
  - After *1 day (5 minutes in demo)* or if power drops too much (adaptive)
    - rotate sentries to balance energy consumption

Sentry Power

Demo Scenario

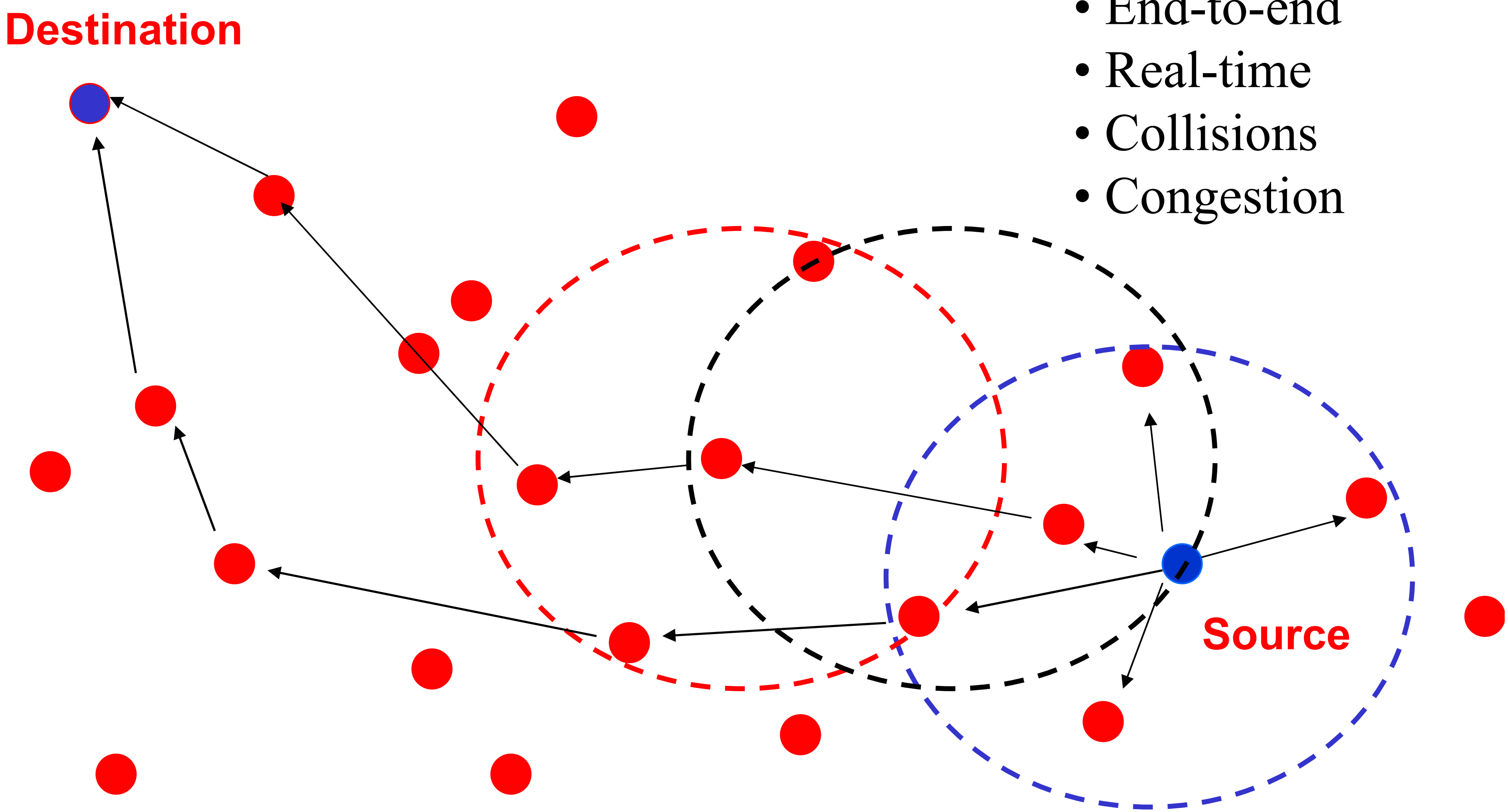
- Phase V - Detect Person
  - Wireless download of new mission functionality (system adapting to new missions)
  - Person walks through the area and is now detected
  - Turn on cameras
  - Vehicles still detected

Adaptive Parameters

- Times of rounds
- Sleep/wakeup times
- Confidence levels for false alarm processing
- Thresholds for sensors
- Communication ranges
- Power savings policies (awake, idle, sleep,…)
- Active density required
- Forwarding range on group management
- Etc.

Sensor Net Adaptive Routing

- End-to-end
- Real-time
- Collisions
- Congestion



Assumption: Nodes know location

Sensor Network Routing

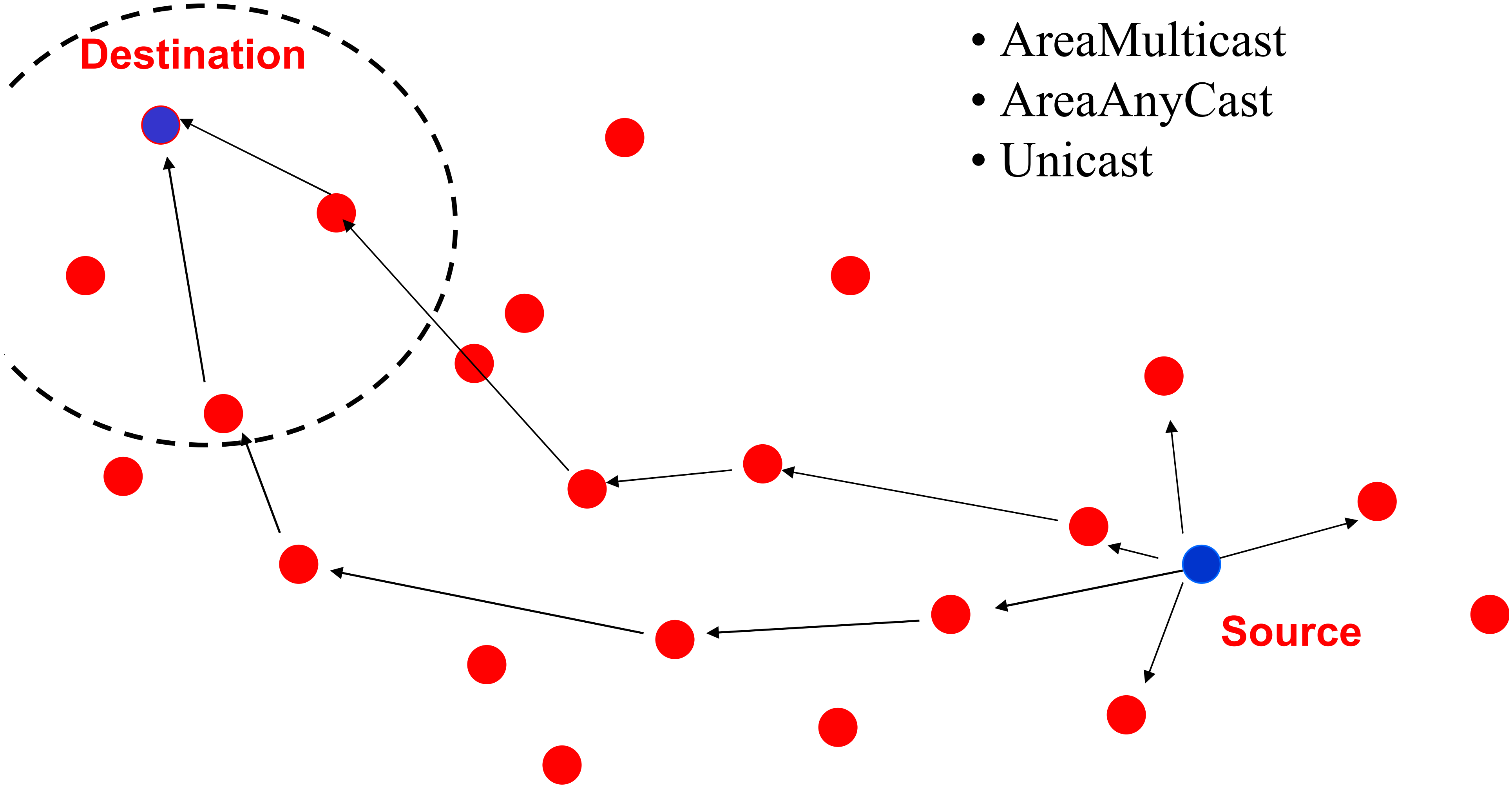
- Current solutions
  - DSDV needs routing tables the size of the network
  - Most use single path to destination (DSR, AODV,…)
  - Many use path finding beacons - bad for real-time
- SPEED (first to deal with soft real-time in WSN)
  - local (neighbor) tables only
  - utilize multiple paths
  - no set-up beacons needed

SPEED Protocol

- API (and last mile processing)
- Neighbor Beacon Exchange
- Delay Estimation Scheme
- Neighborhood Feedback Loop (NFL)
  - Maintains single hop relay speed
- Semi-Stateless Non-deterministic Geographic Forwarding (SNGF)
- Back-pressure Re-routing
- Void Avoidance

API (Last Mile Processing)

- AreaMulticast
- AreaAnyCast
- Unicast



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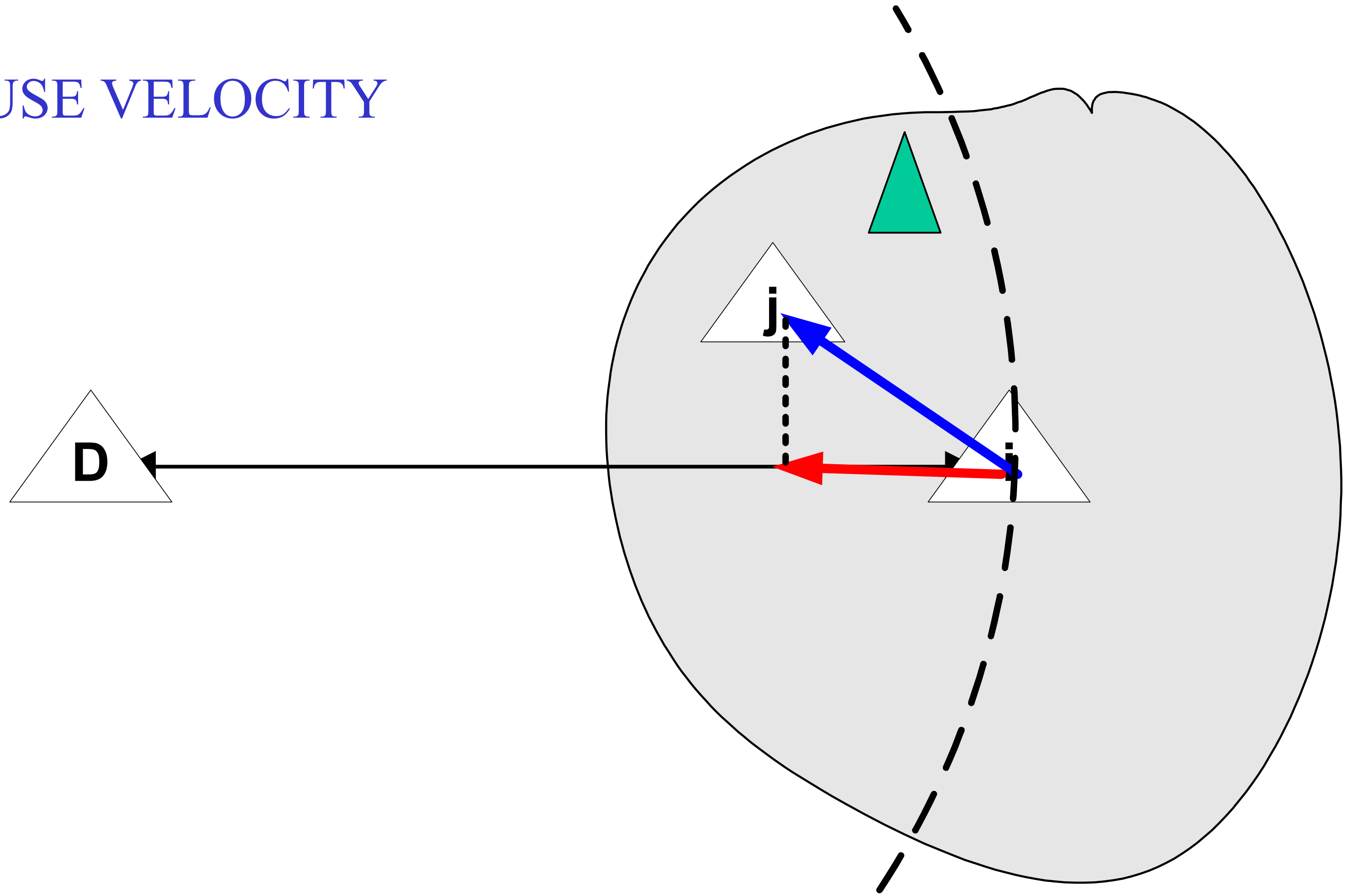
SPEED

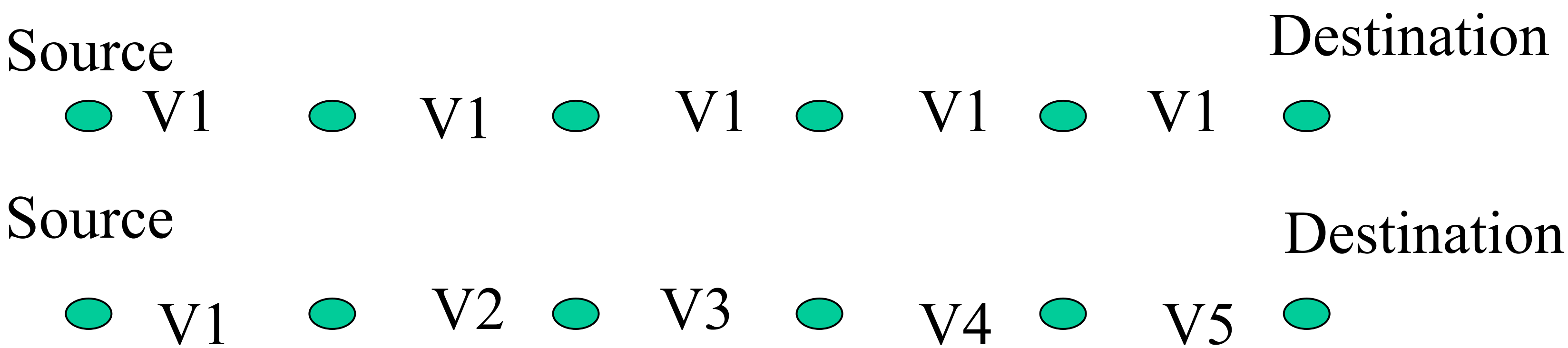
USE VELOCITY



E2E Delay is bound by E2E Distance/Speed SetPoint

RAP

- Velocity Monotonic Scheduling (HVF)
  - Static – compute velocity at source and maintain throughout every hop
  - Dynamic – change velocity at each hop depending on the current time and distance



Nondeterministic Forwarding

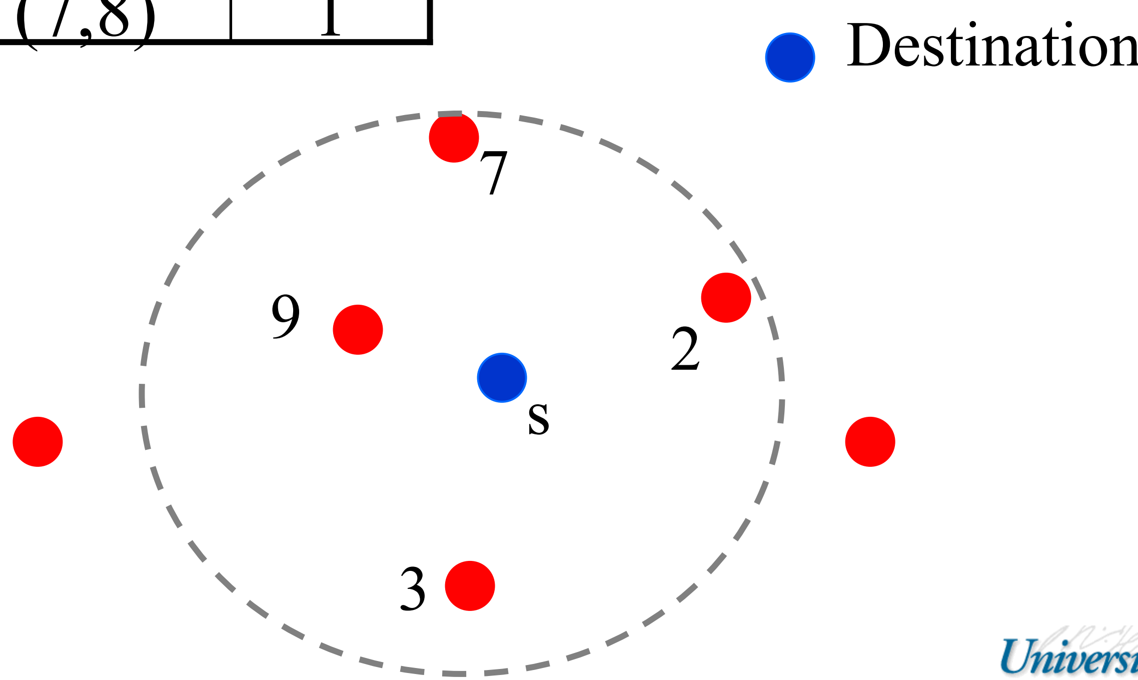
Example 1:

RP: Relay probability

ID	Position	Delay
9	(1,6)	5
7	(3,4)	3
3	(4,7)	3
2	(7,8)	1

Compute Speed

ID	Position	RP
2	(7,8)	100%



Nondeterministic Forwarding

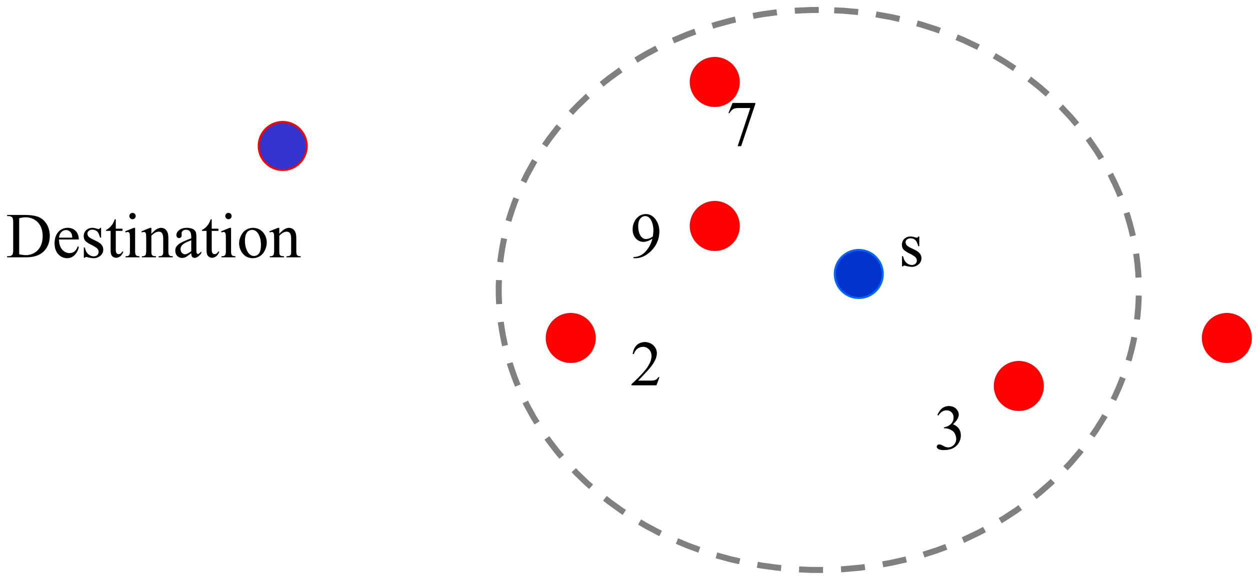
Example 2:

RP: Relay probability

ID	Position	Delay
9	(1,6)	2
7	(3,4)	6
3	(4,7)	1
2	(7,8)	3

Compute Speed

ID	Position	RP
9	(1,6)	50%
2	(7,8)	50%



Nondeterministic Forwarding

Example: Overload situation

Example 3:

ID	Position	Delay
9	(x,y)	1
7	(3,4)	4
3	(4,7)	5
2	(7,8)	2

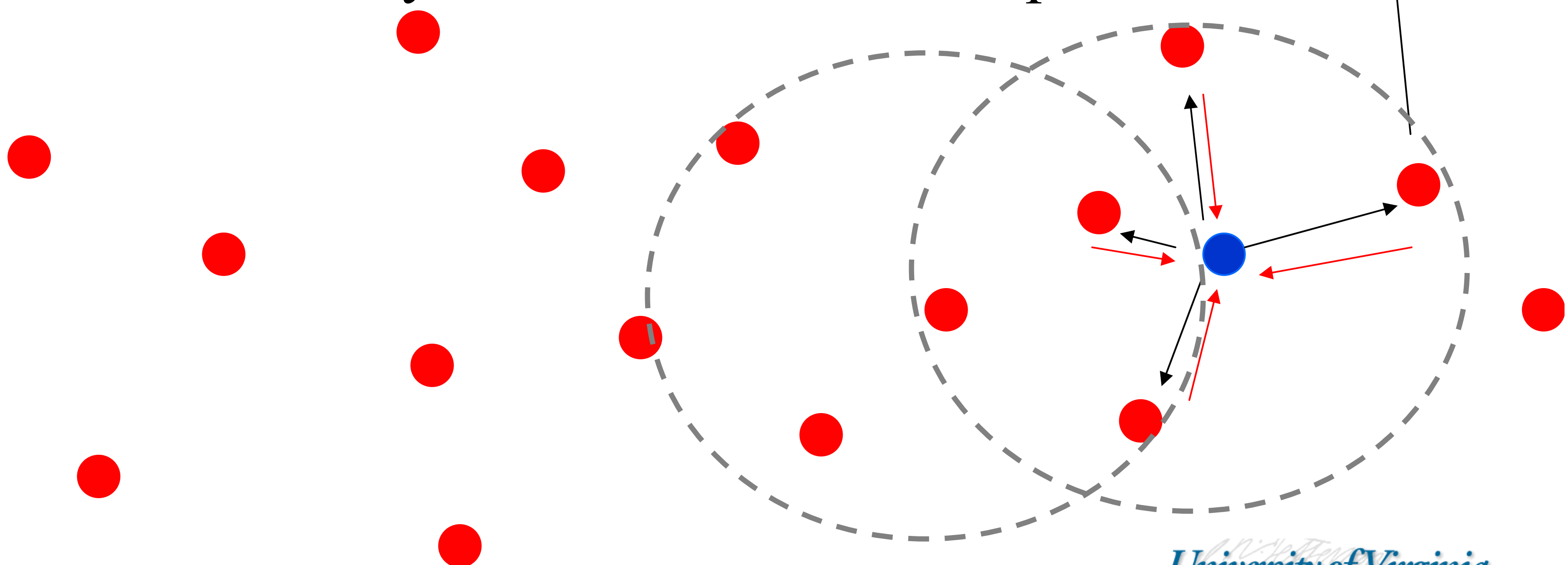
Compute Speed

ID	Position	RP
7	(3,4)	45%
3	(4,7)	40%
Drop		15%

Drop ratio is computed according to the Neighborhood feedback control loop

Feedback Control

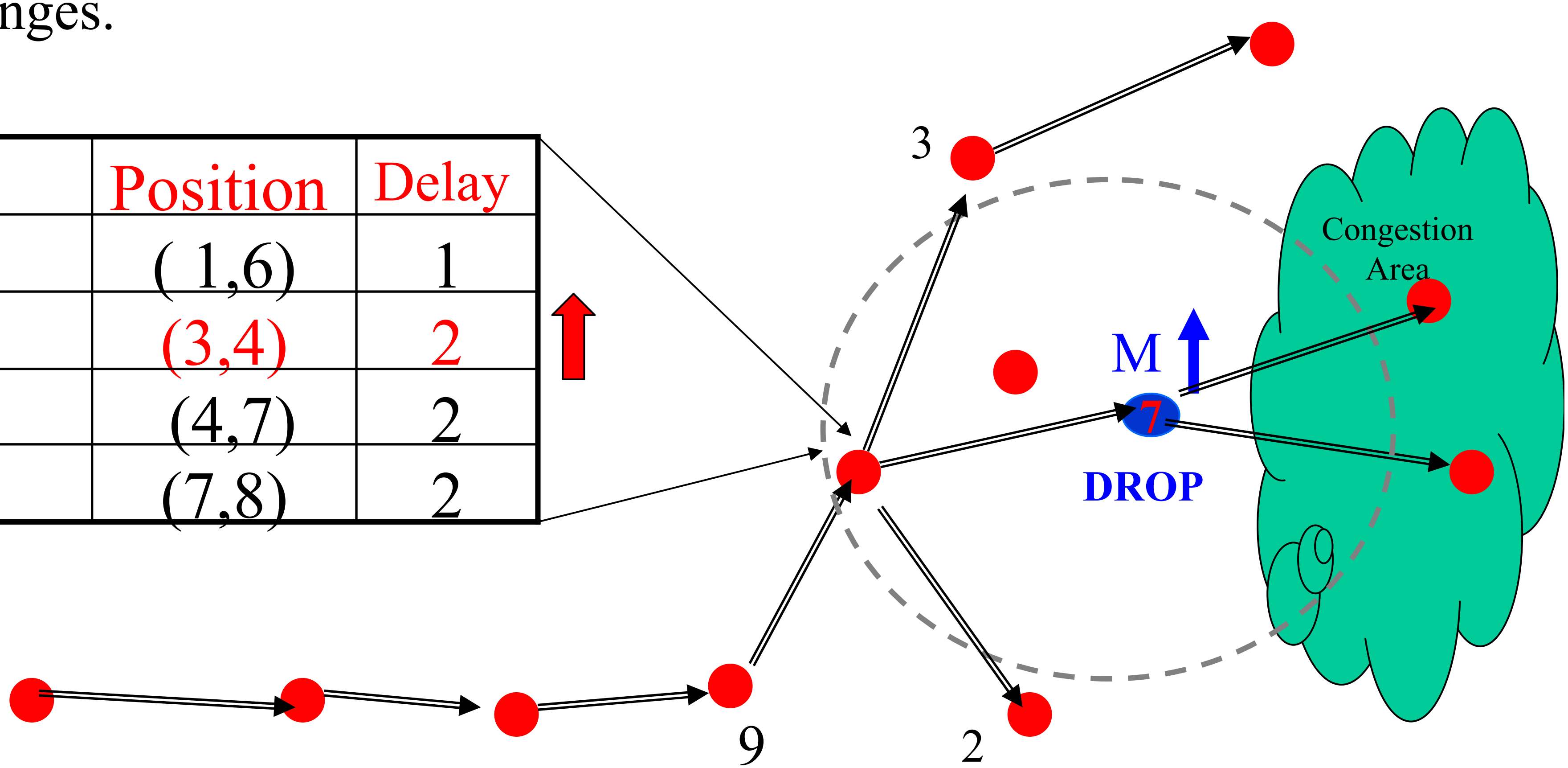
- Collect miss ratio from neighbors
- MISO P controller
- Calculate the relay ratio
- Activated only when no valid next hop



Back-pressure Re-routing

- When all available forwarding nodes are congested, the sending node will drop packets, which is perceived by previous nodes. Route changes.

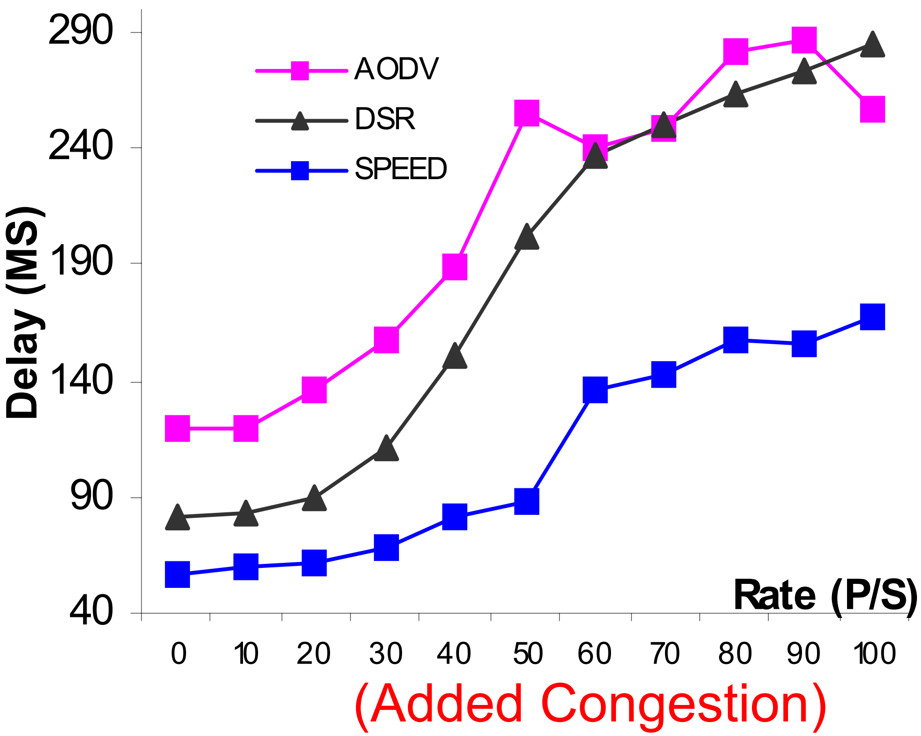
ID	Position	Delay
9	(1,6)	1
7	(3,4)	2
3	(4,7)	2
2	(7,8)	2



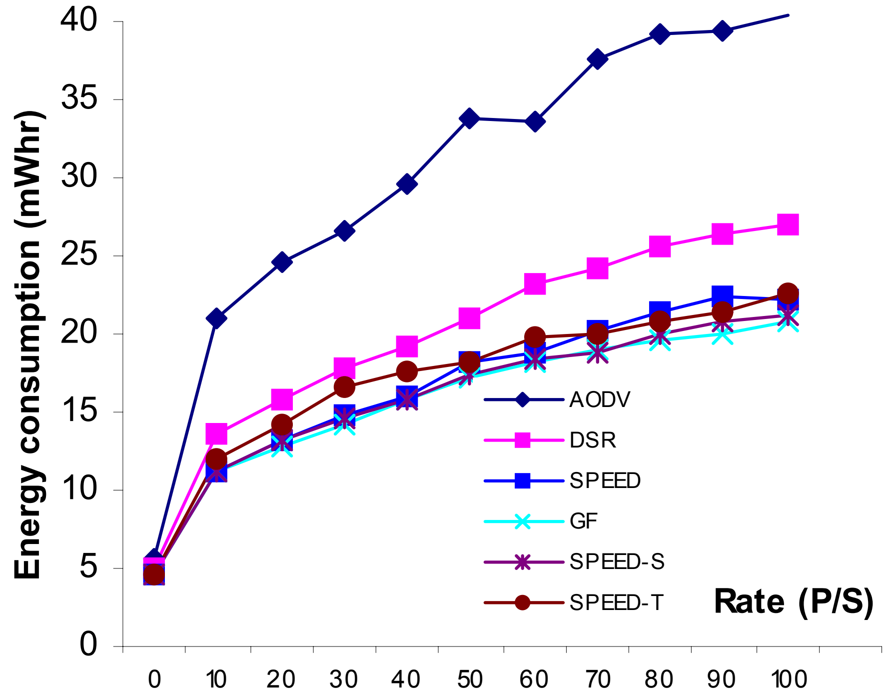
Evaluation

- 6 CBR flows on right side of terrain send to one base station on right side of terrain
- average number of hops (8-9)
- 90% CI (within 2-10% of mean)
- *Under heavy congestion*
  - *added flows in center of terrain*
- *Transient performance*

Evaluation



E2E Delay



Energy Consumption

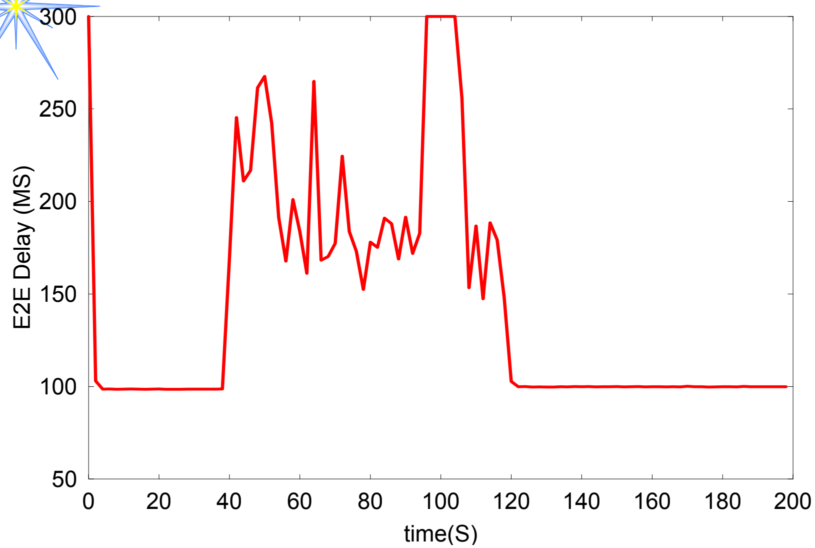


Figure A. E2E delay profile of DSR

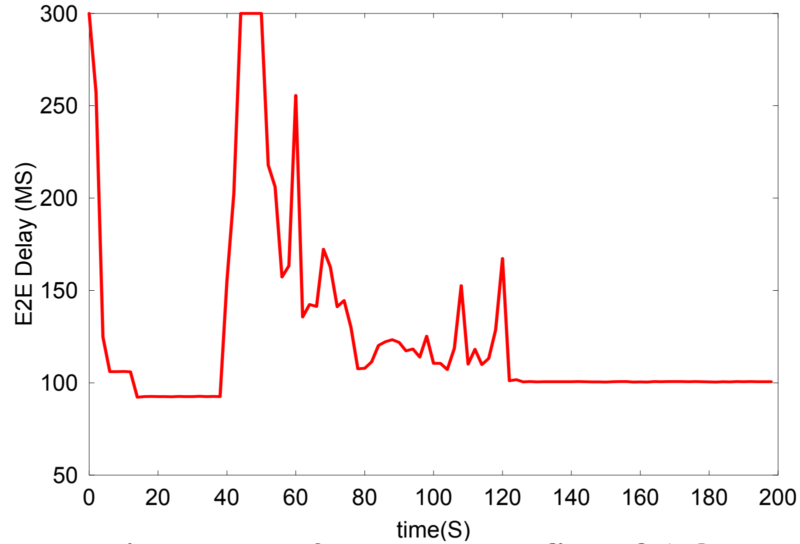


Figure B. E2E delay profile of AODV

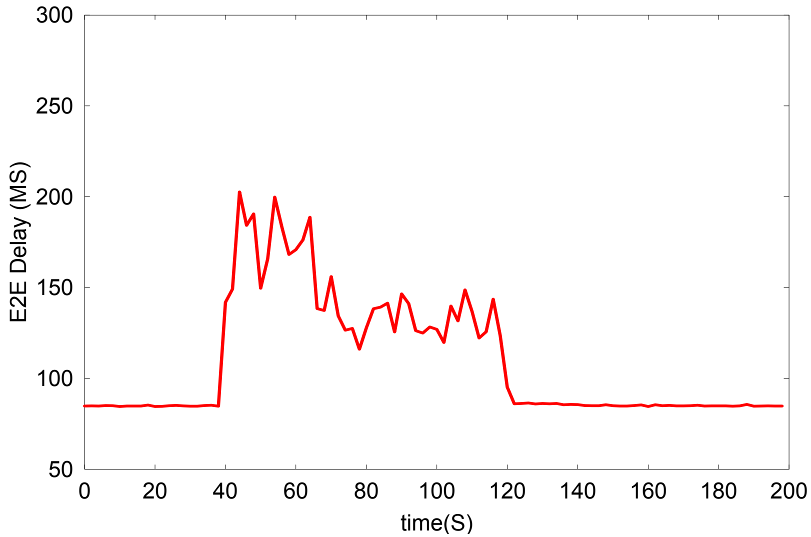


Figure C. E2E delay profile of GF

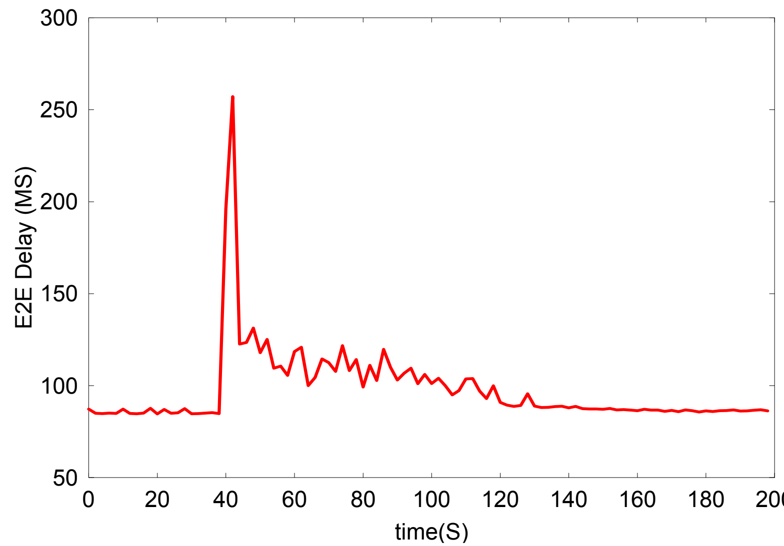


Figure D E2E delay profile of SPEED

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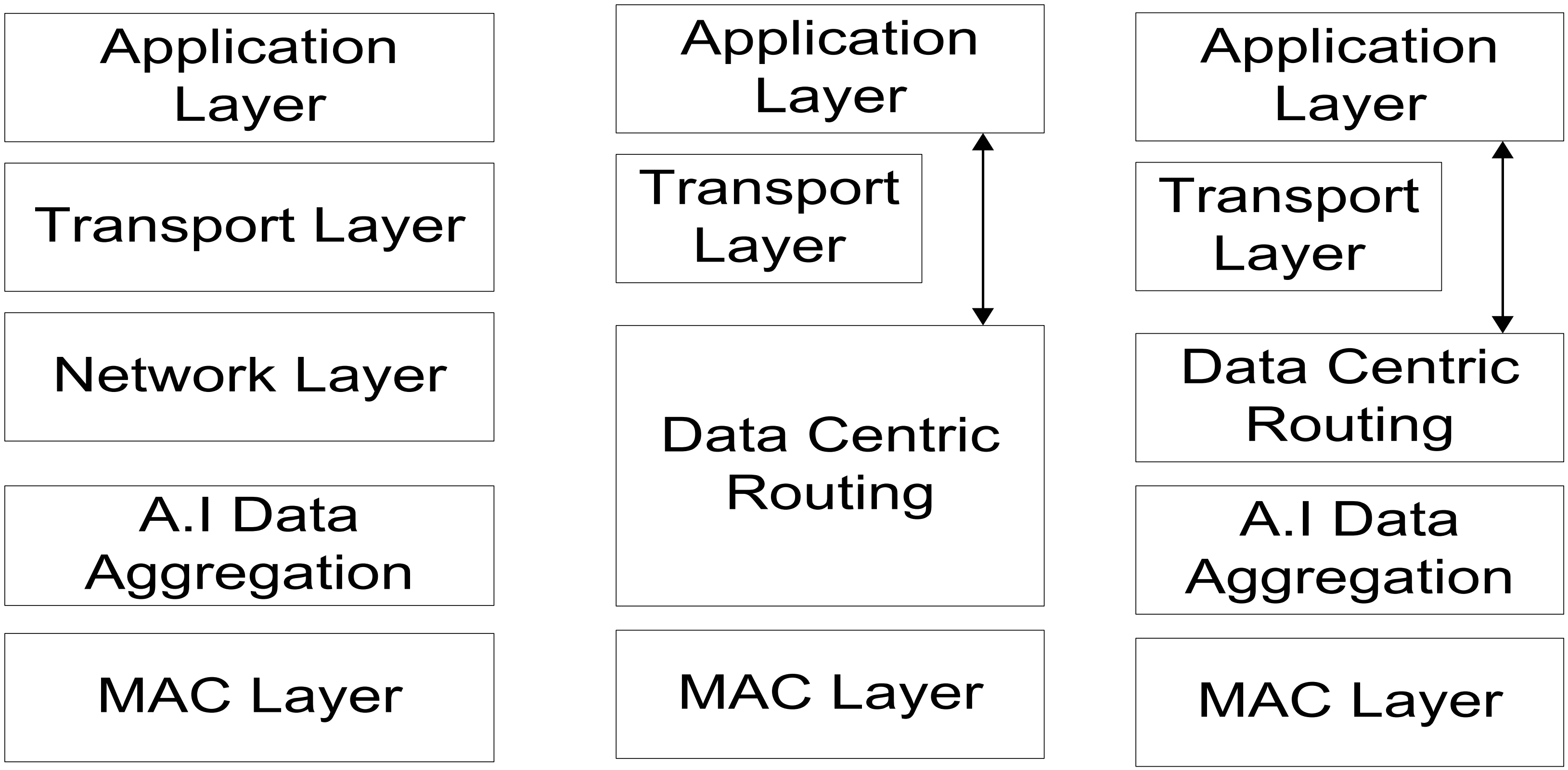
Application Independent Data Aggregation

- Expensive to acquire the “channel”
- Small data packets
- Group data packets into 1 MAC packet
- Works *in addition to* other data aggregation techniques which are based on semantics

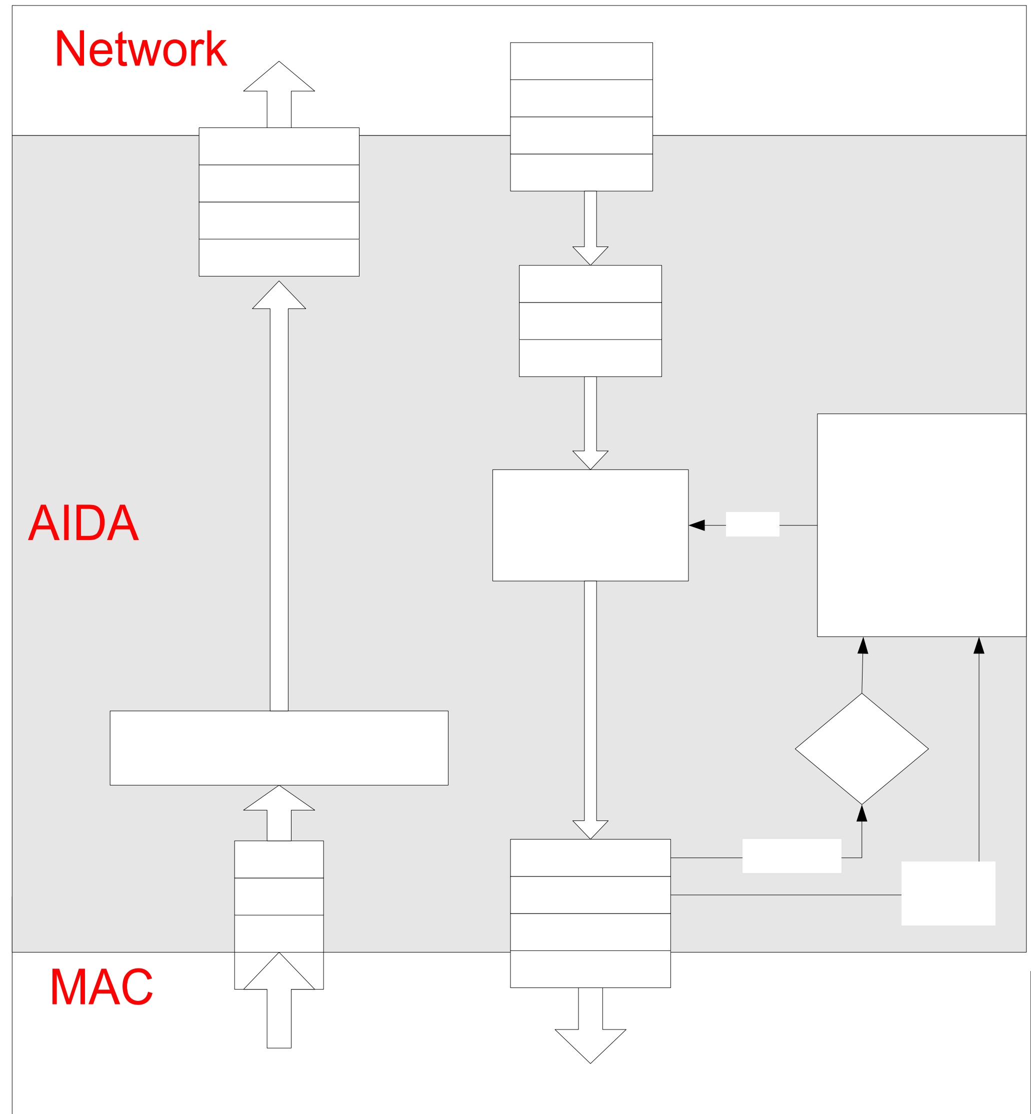
Major Architectural Difference



a. AIDA b. ADDA c. Both

DYNAMIC/Adaptive FC

- Adaptive choice of N
- Take into account the output Queue delay
- Delay is used to adjust the output queue push rate and degree of aggregation



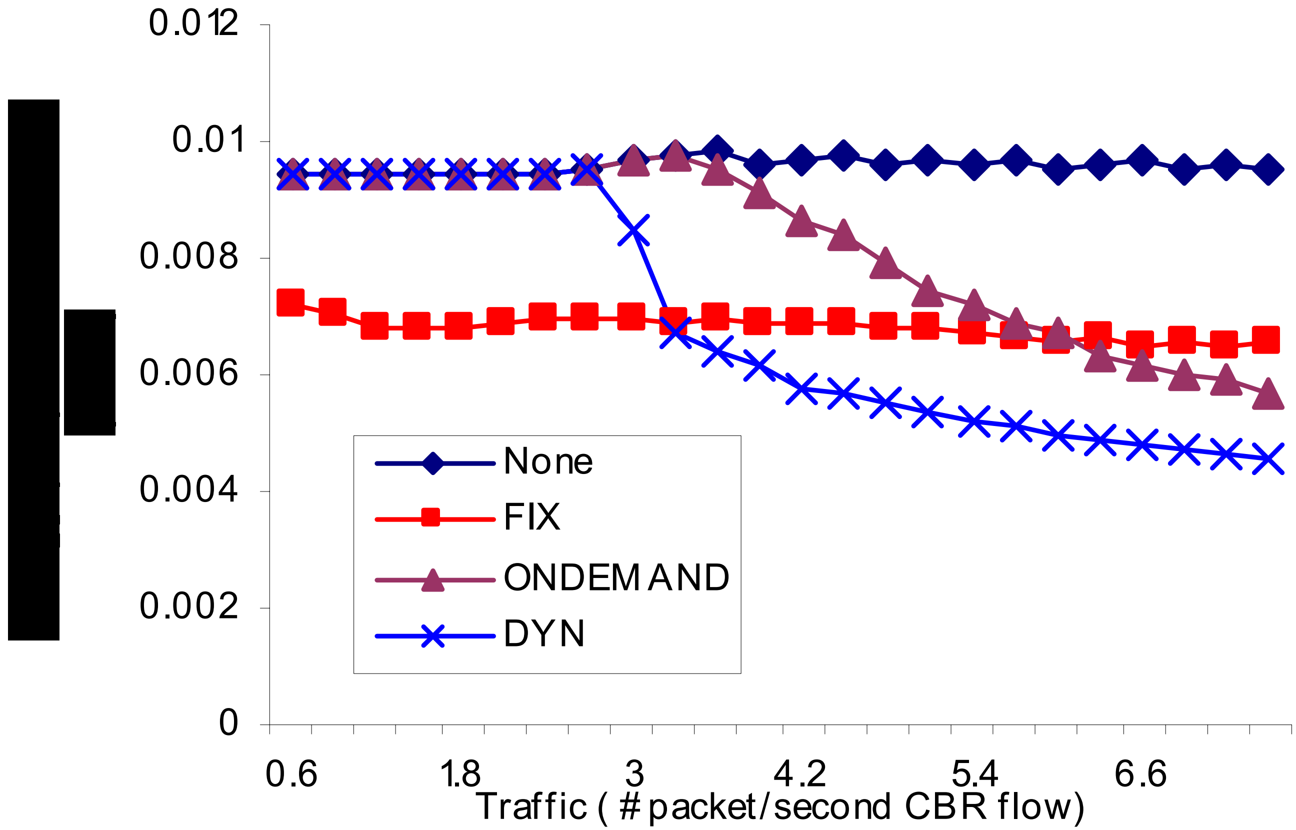


Figure 17: Energy per unit delivered (many-to-one)

50% reduction

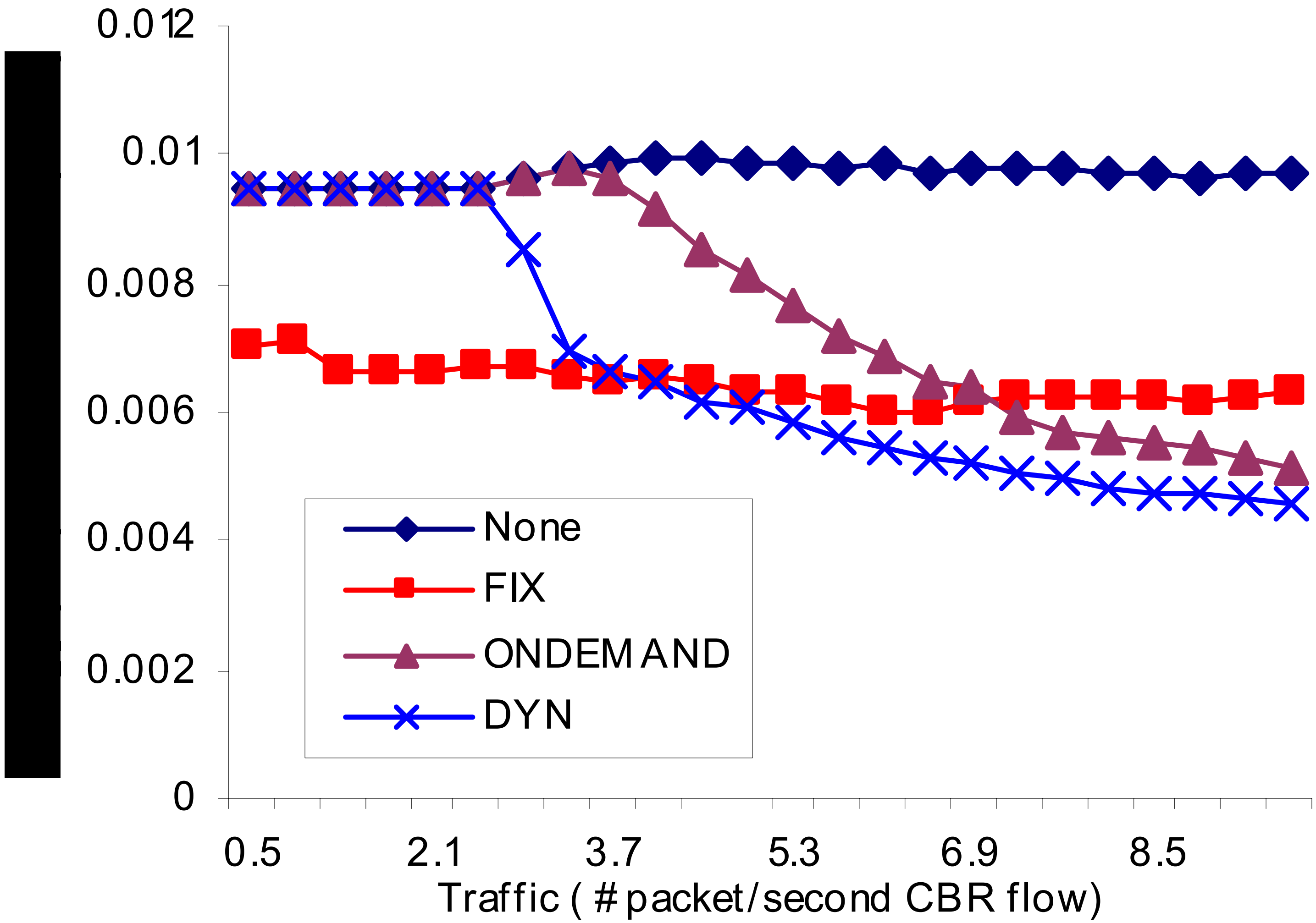
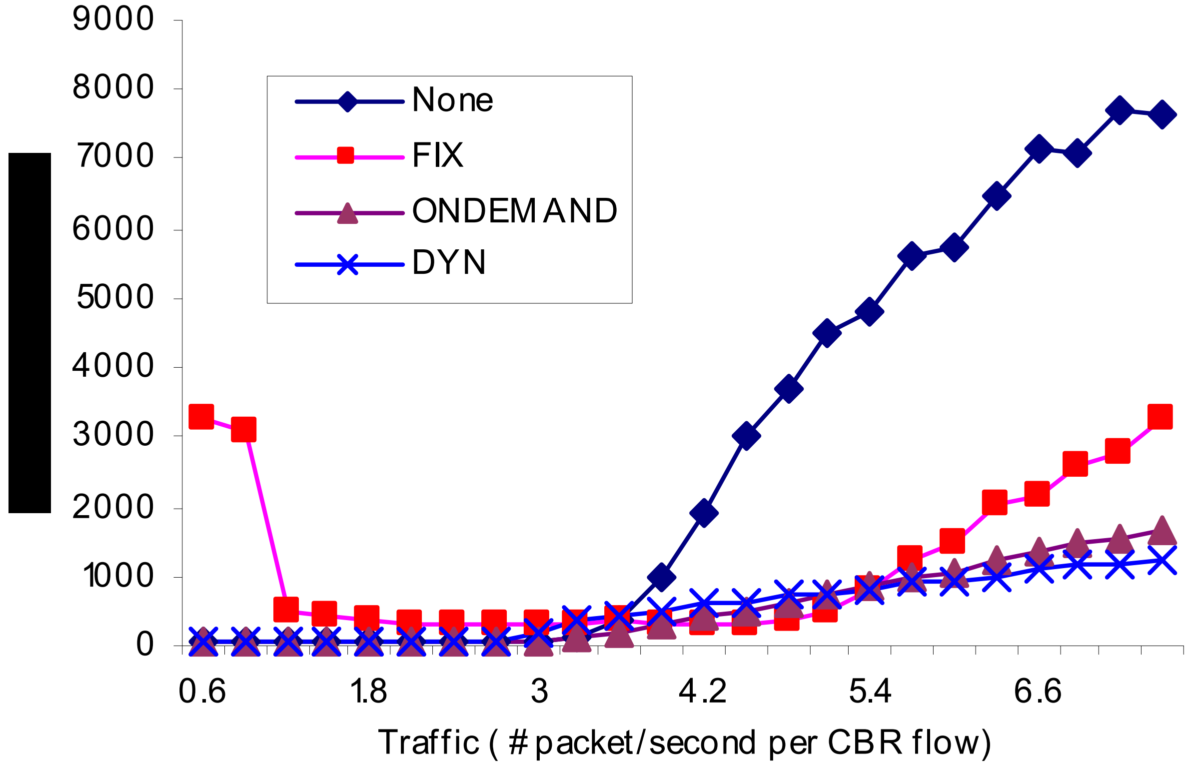


Figure 18: Energy per unit delivered (many-to-many)

50% reduction

Evaluation



E2E Delay

80% reduction

Summary

- WSN need to be highly adaptive in many dimensions
  - Use FC for some solutions
- Next generation real-time system
  - Just scratching the surface with respect to real-time constraints
  - OS ⇔ Middleware

Publications

SPEED: A Stateless Protocol for Real-Time Communication in Sensor Networks, T. He, J. Stankovic, C. Lu, and T. Abdelzaher, IEEE International Conference on Distributed Systems, May 2003. 1 of 5 nominated for best paper award (407 submissions).

AIDA: An Adaptive Application Independent Data Aggregation Protocol,T. He, B. Blum, J. Stankovic, T. Abdelzaher, to appear *ACM Transactions on Embedded Computing Systems (special issue)*.

Range-Free Localization Schemes for Large Scale Sensor Networks, T.He, C. Huang, B. Blum, J. Stankovic, and T. Abdelzaher, In Mobicom, Sept. 2003.

RAP: A Real-Time Communication Architecture for large Scale Wireless Sensor Networks, C. Lu, B. Blum, T. Abdelzaher, J. Stankovic, and T. He, RTAS, June 2002.

Publications

Differentiated Surveillance for Sensor Networks, T. Yang, T. He and J. Stankovic, Sensys 2003, to appear.

JAM: A Mapping Service for Wireless Sensor Networks, A. Wood, J. Stankovic and S. Son, RTSS 2003, to appear.

Envirotrack: Towards an Environmental Computing Paradigm for Distributed Sensor Networks, T. Abdelzaher, et. al., submitted for publication.