Modelling Wireless Sensor Networks

Usman Khan

RTS Research Group

RTS York

THE UNIVERSITY of York

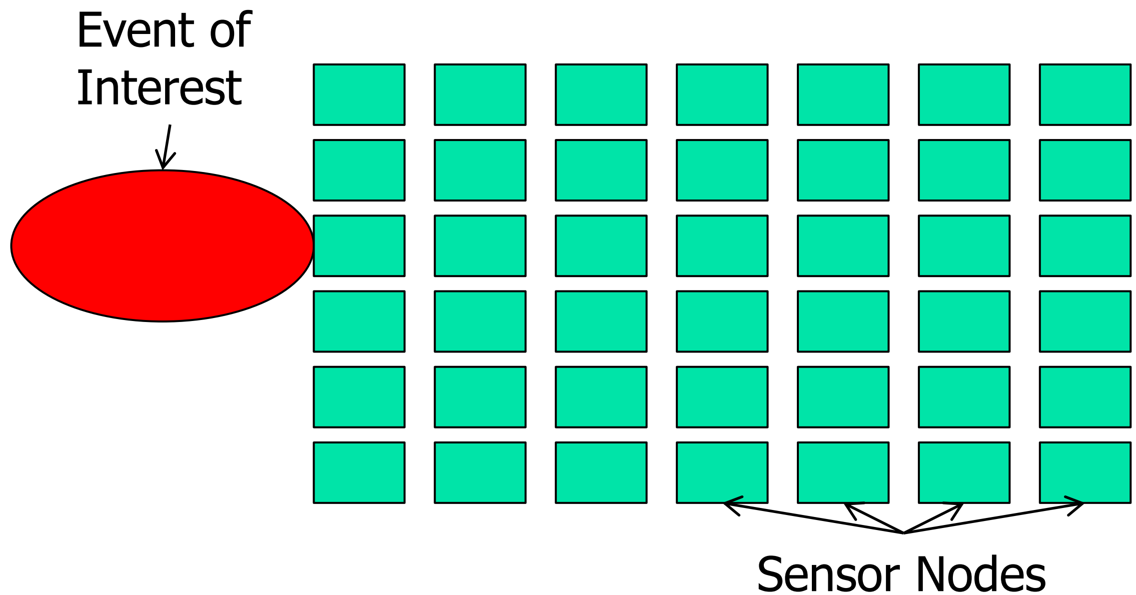
Overview

- Introduction to WSN
- WSN Categorisation & Protocols
- WSN Architecture
- Modelling WSN
  - Goals & Challenges
  - Simulators and Models
- Summary

WSN: Introduction

- Consist of numerous Sensor Nodes
  - Spatially Distributed
  - Densely Deployed
  - Autonomous
  - Scarce Power Resources (e.g. 2 AA batteries on a node - ~4000 mAh)

WSN Demo



- Limited Sensing Range (~10m)
- Larger Communication Range (~50m)

RTS York THE UNIVERSITY of York

Sensor Nodes

- Consist of
  - Sensors
  - Processing
  - Communication
- Node Categories
  - Base Station / Sink
  - Source
  - Relay Nodes

Mica Sensor Node

WSN Categorisation

- Deployment
- Mobility
- Bandwidth
- Deployed Location
- Activation Scheme

Communication Protocols

- Physical Layer
- Data Link Layer
- Network Layer
- Transport Layer
- Application Layer

Data Link Layer

- MAC
  - Collisions waste energy; need to be minimised
- Power Saving Modes
- Error Control
  - FEC
    - Enables a given BER at lower transmit power
    - Processing power overhead

Network Layer - Routing

- Data-centric vs. address-centric
- Attribute-based
- Routing Strategies
  - Flooding, Gossiping
  - Geographic Forwarding, e.g. GEAR,GAF
  - Directed Diffusion
  - Distance Vector, e.g. DSR,DSDV,AODV
  - Hierarchical, e.g. MMMH

Network Layer - Routing

- Routing Heuristics
  - Shortest
  - Fastest
  - Minimal Power Consumption
  - Average Remaining Power in route nodes
  - Minimum Remaining Power in route nodes

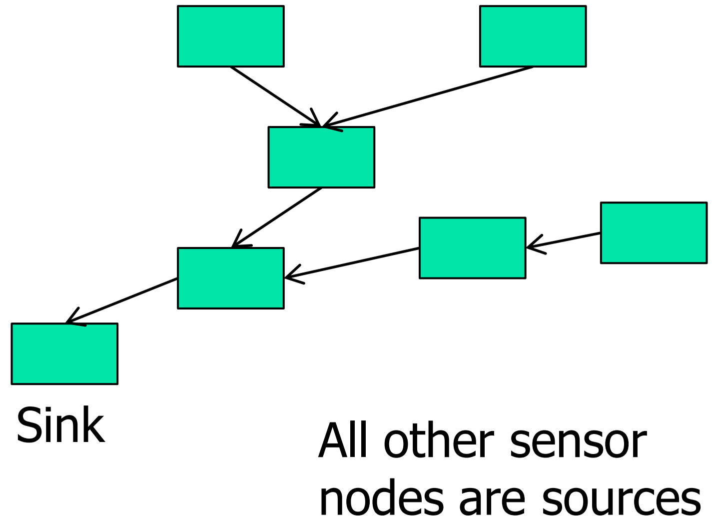
WSN Architecture

- Sensor Node OS
- Storage
- Communication
- Services
  - Location
  - Aggregation
  - Synchronisation
  - Security

Services - Location

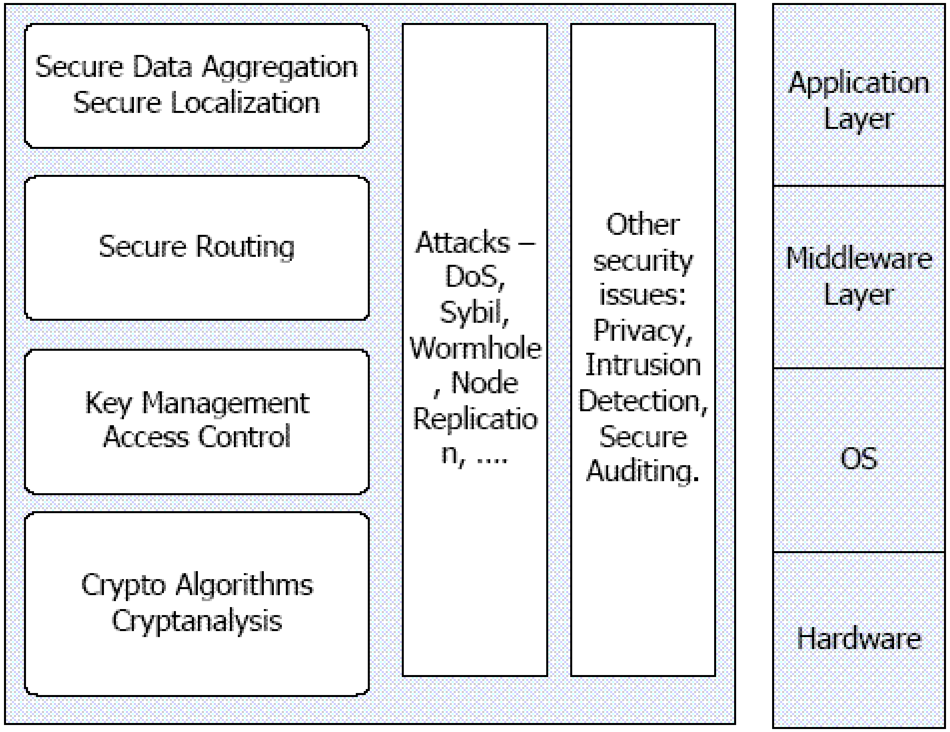
- Geographical Location-Aware Nodes using
  - GPS
  - IMU
- Relative Position
  - To Fixed Reference Points
  - To Other Nodes

Services - Aggregation



- Compression
  - Transmission Power cost dominates Processing and Sensing

Services - Security



WSN Security Issues
(http://www.wsn-security.info, Last accessed: 9th June 2011)

Modelling WSN: Goals

- Analysis of Power Consumption
- Network Longevity Analysis
- WSN Protocol Evaluation
- WSN Architecture Evaluation
- Facilitate Optimisation

Modelling WSN: Challenges

- Hardware Dependency
- OS Dependency
- Environmental Dependency
- Battery Dependency
- Need to validate model
- Portability required across platforms

Modelling WSN

- Simulators
  - Atemu, Avrora
  - TOSSIM, PowerTOSSIM
  - NS2, NS3 (has WSN libraries)
- Models
  - Independent of Node hardware/OS
  - Assumes Minimal Hardware Overhead
  - Validation with measurements needed

Simulators

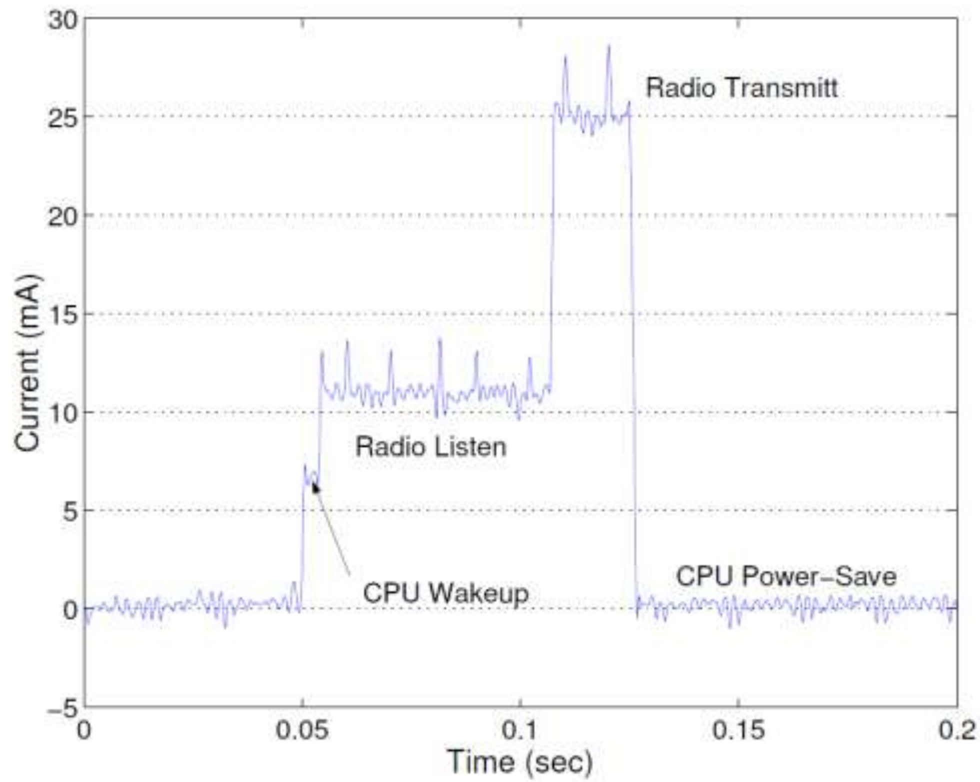
- PowerTOSSIM
  - Power Consumption Estimator
  - Per node
  - Built as addition to TOSSIM
  - TOSSIM: Tiny OS Simulator
  - First measured CPU, Radio, Memory Power Consumption

PowerTOSSIM

Mode	Current	Mode	Current
CPU		**Radio**	
Active	8.0 mA	Rx	7.0 mA
Idle	3.2 mA	Tx (-20 dBm)	3.7 mA
ADC Noise Reduce	1.0 mA	Tx (-19 dBm)	5.2 mA
Power-down	103 μA	Tx (-15 dBm)	5.4 mA
Power-save	110 μA	Tx (-8 dBm)	6.5 mA
Standby	216 μA	Tx (-5 dBm)	7.1 mA
Extended Standby	223 μA	Tx (0 dBm)	8.5 mA
Internal Oscillator	0.93 mA	Tx (+4 dBm)	11.6 mA
LEDs	2.2 mA	Tx (+6 dBm)	13.8 mA
Sensor board	0.7 mA	Tx (+8 dBm)	17.4 mA
EEPROM access		Tx (+10 dBm)	21.5 mA
Read	6.2 mA		
Read Time	565 μs		
Write	18.4 mA		
Write Time	12.9 ms		

Mica2 Components Power Consumption (Shnayder et al., 2004)

PowerTOSSIM



Mica2: Current Consumption for transmitting 1 radio message (Shnayder et al., 2004)

PowerTOSSIM

- PowerState software module built
- Instrumented simulated hardware modules with calls to PowerState
- Power state transitions logged

PowerTOSSIM

Application	CPU idle	CPU active	Radio	Leds	Sensor Board	EEPROM	Total
Beacon	35.86	0.58	47.68	8.81	0.00	0.00	92.93
Blink	742.50	0.25	0.00	197.52	0.00	0.00	940.26
BlinkTask	742.50	0.27	0.00	197.52	0.00	0.00	940.28
CntToLeds	743.72	0.57	0.00	592.20	0.00	0.00	1336.49
CntToLedsAndRfm	741.90	1.61	1284.65	592.20	0.00	0.00	2620.37
CntToRfm	741.90	1.54	1284.65	0.00	0.00	0.00	2028.09
Oscilloscope	742.65	1.46	0.00	0.00	123.82	0.00	867.94
OscilloscopeRF	741.90	1.85	1268.76	0.00	123.95	0.00	2136.45
Sense	742.21	0.38	0.00	0.00	123.00	0.00	865.59
SenseLightToLog	741.90	0.81	1262.95	0.00	123.95	4.28	2133.89
SenseTask	742.21	0.42	0.00	0.00	123.00	0.00	865.62
SenseToLeds	743.72	0.73	0.00	0.00	124.25	0.00	868.70
SenseToRfm	741.90	1.77	1284.65	0.00	123.95	0.00	2152.27
TinyDB (idle)	693.29	10.41	1181.78	0.00	115.83	0.00	2001.31
TinyDBApp (select)	742.85	11.20	1266.70	0.00	124.11	0.00	2144.86
Surge	727.28	1.50	1239.02	0.00	121.30	0.00	2089.09

Simulated Application Energy Consumption by Component
(Shnayder et al., 2004)

PowerTOSSIM

Benchmark	Simulated	Measured	Error (%)
Beacon	92.93	106.73	-12.9
Blink	940.26	931.72	0.85
BlinkTask	940.28	917.90	2.5
CntToLeds	1336.49	1330.00	0.45
CntToLedsAndRfm	2620.37	2562.00	2.3
CntToRfm	2028.09	1985.00	2.1
Oscilloscope	867.94	801.60	8.3
OscilloscopeRF	2136.45	2021.90	5.7
Sense	865.59	900.72	-3.8
SenseLightToLog	2133.89	2005.26	6.4
SenseTask	865.62	944.74	-8.3
SenseToLeds	868.70	977.73	-11.1
SenseToRfm	2152.27	2059.16	4.5
Average			4.7
TinyDB (idle)	2001.31	2275.55	-12.1
TinyDB (select light)	2144.86	2465.30	-13.0
Surge	2089.09	2028.40	3.0
Average			9.5

Measured vs. Simulated Energy usage for TinyOS applications
(Shnayder et al., 2004)

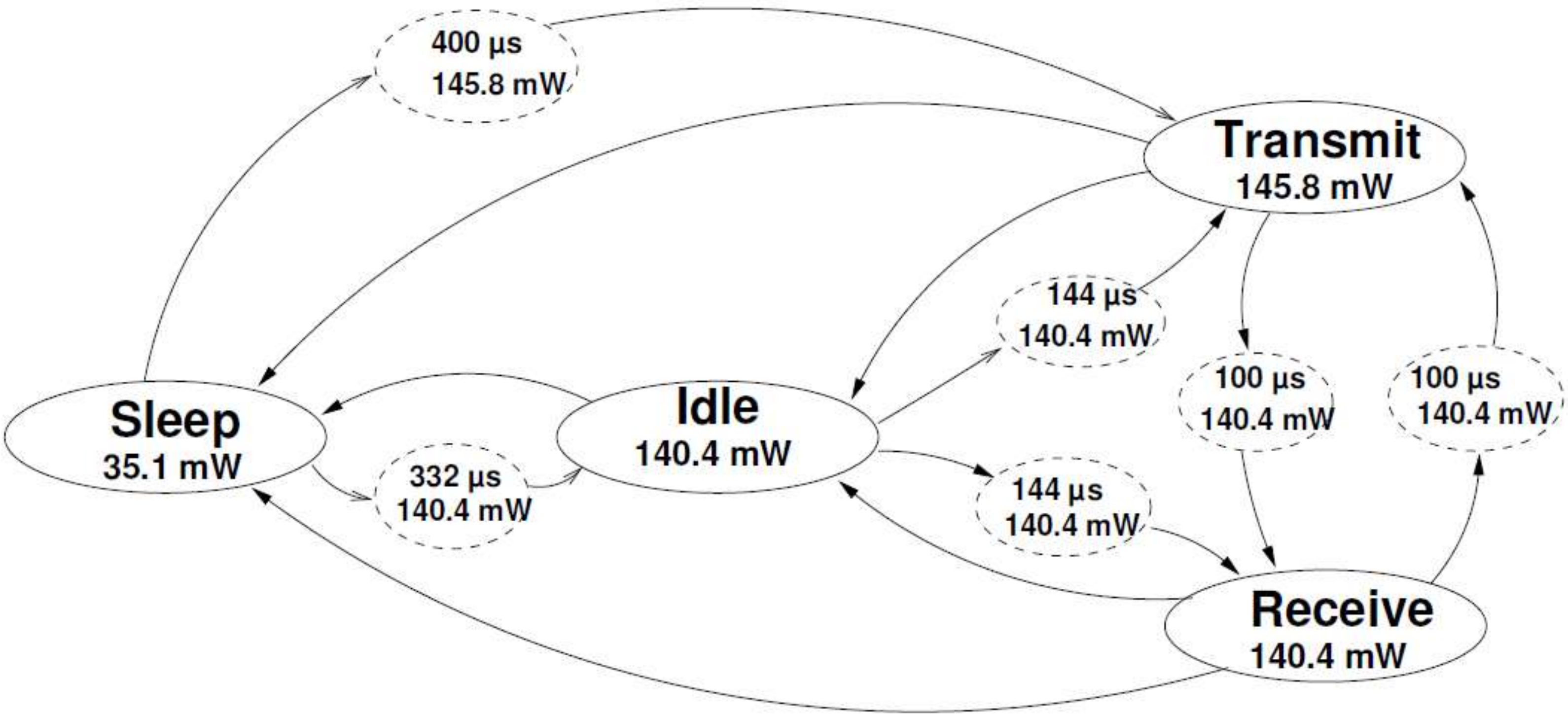
PowerTOSSIM: Evaluation

- Scalable
- Limited to measured hardware
- Portable by hardware extension
- Environmental model needed

Models

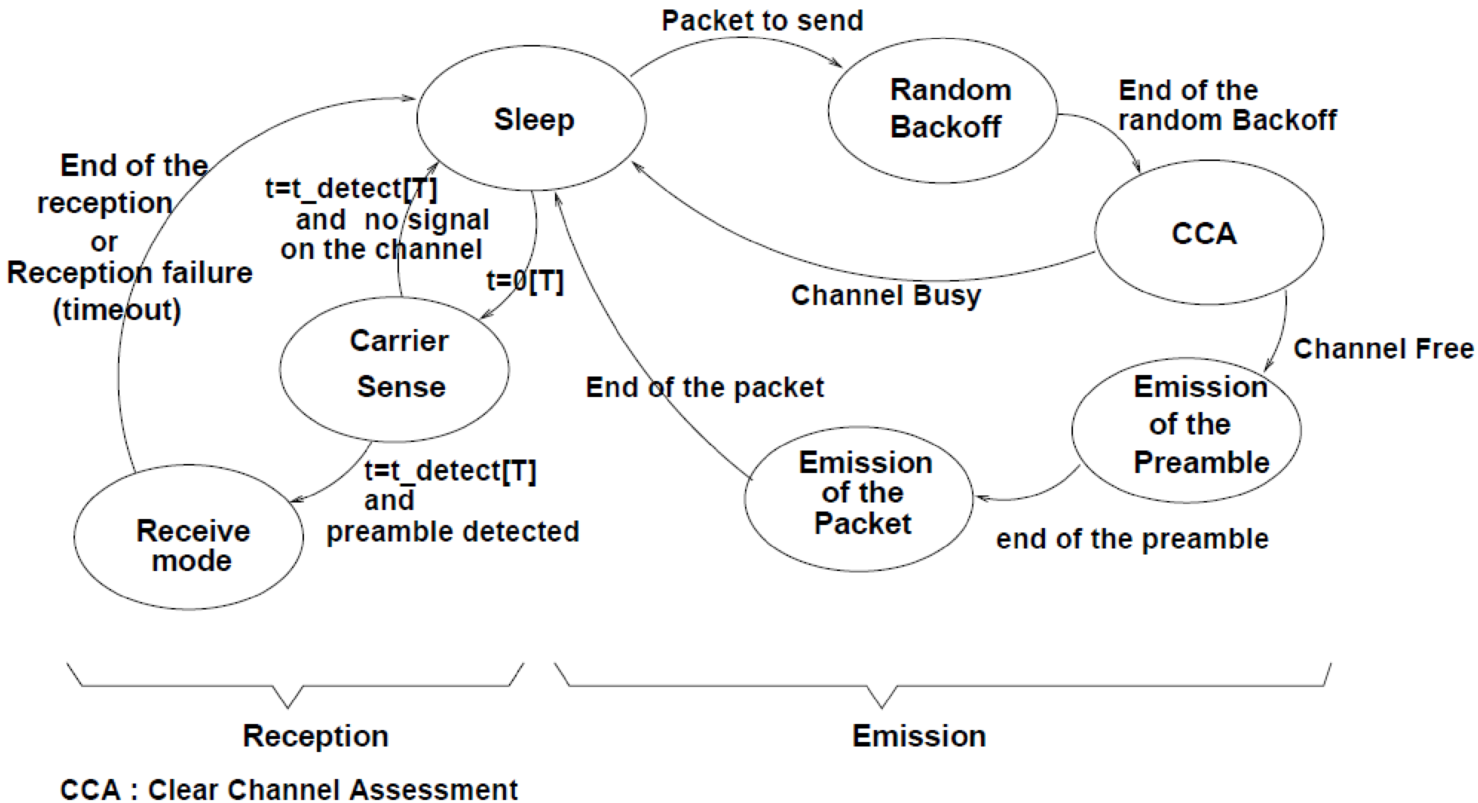
- GLONEMO
  - Models WSN Power Consumption
  - Provides Models for:
    - Node Radio
    - Communications Protocol
    - Application
    - Environment

GLONEMO



Radio states energy consumption (Samper et al., 2006)

GLONEMO



MAC Protocol Functional Model (Samper et al., 2006)

GLONEMO

- MAC Protocol states coupled with node radio states
- Routing Protocol implemented on MAC Protocol
- Application implemented on Routing Protocol
- Independent Environment Model
  - e.g. Movement of radioactive cloud

GLONEMO: Evaluation

- Model amenable to analysis
- Portable – hardware independent
- Validation required
- CPU, Sensors, Memory, Sensor Board Power Models needed
- Proof required of negligible hardware, OS overhead

Summary

- WSN Models and Simulators shown
- Modelling approach is hardware/OS-independent
- Next step
  - Create a small model (5 node WSN)
  - Implement Flooding with TDMA MAC
  - Validate measured power usage with real deployment

References

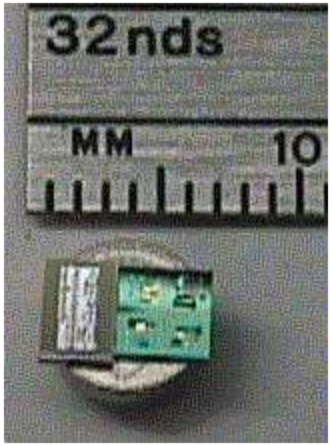
1) Jennifer Yick, Biswanath Mukherjee, and Dipak Ghosal. Wireless sensor network survey. *Comput. Netw.*, 52:2292-2330, August 2008.
2) I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci. Wireless sensor networks: a survey. *Computer Networks*, 38(4):393-422, March 2002.
3) Victor Shnayder, Mark Hempstead, Bor R. Chen, Geoff W. Allen, and Matt Welsh. Simulating the power consumption of large-scale sensor network applications. In *Proceedings of the 2nd international conference on Embedded networked sensor systems*, SenSys '04, pages 188-200, New York, NY, USA, 2004. ACM.
4) Ludovic Samper, Florence Maraninchi, Laurent Mounier, and Louis Mandel. GLONEMO: global and accurate formal models for the analysis of ad-hoc sensor networks. In *Proceedings of the first international conference on Integrated internet ad hoc and sensor networks*, InterSense '06, New York, NY, USA, 2006. ACM.

References

5) Philip Levis, Sam Madden, Joseph Polastre, Robert Szewczyk, Alec Woo, David Gay, Jason Hill, Matt Welsh, Eric Brewer, and David Culler. TinyOS: An operating system for sensor networks. In *in Ambient Intelligence*, 2004.
6) Fabio Silva, John Heidemann, Ramesh Govindan, and Deborah Estrin. Directed diffusion. Technical report, USC/Information Sciences Institute, January 2004.
7) Wireless sensor networks security. http://www.wsn-security.info. Last accessed: 9th June 2011.

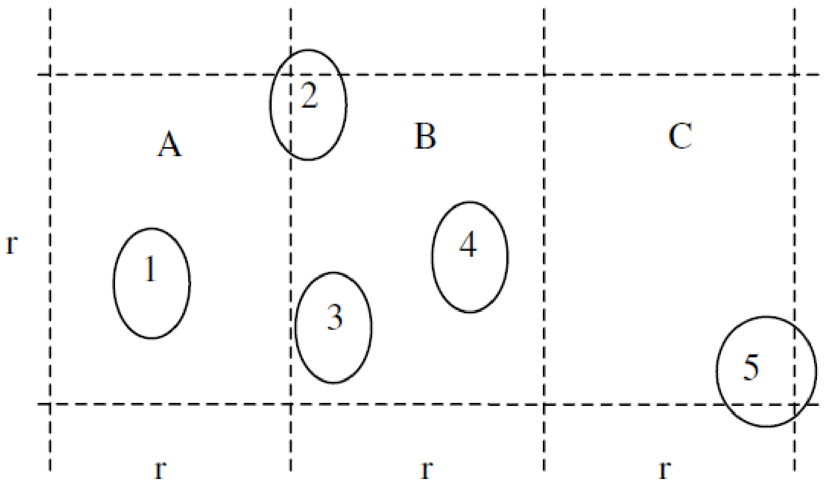
Wireless Sensor Networks

- Pervasive/Ubiquitous Sensors
- ‘Disappearing’ technology
- Smart Dust

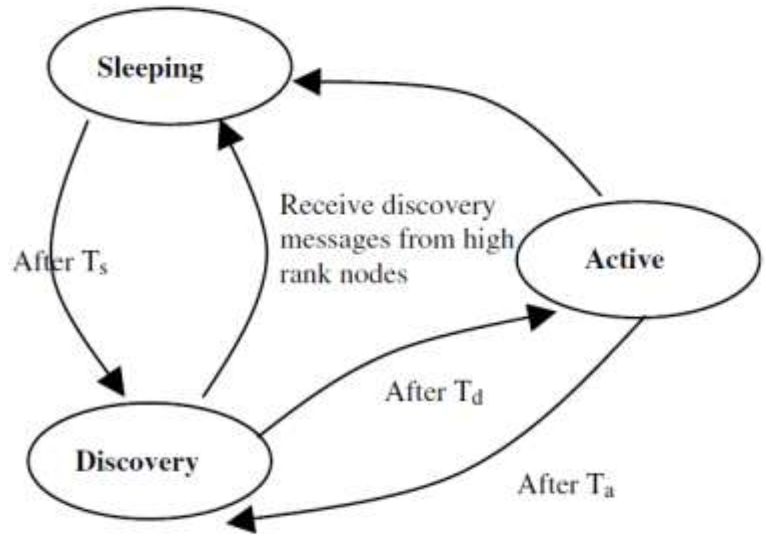


‘Smart Dust’ node size

Geographic Adaptive Fidelity (GAF)



Virtual Grid in GAF
(Akkaya and Younis, 2005)

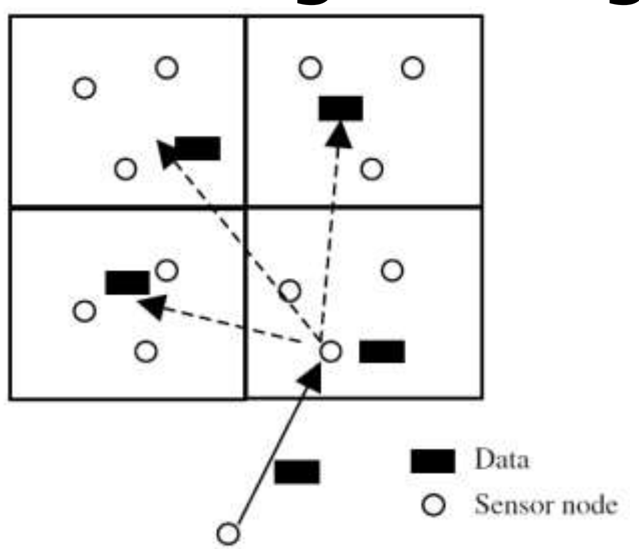


Node State Transitions in GAF
(Akkaya and Younis, 2005)

- Nodes 2, 3 and 4 are in same grid
  - So only 1 need be active at any time

Geographic Energy Aware Routing (GEAR)

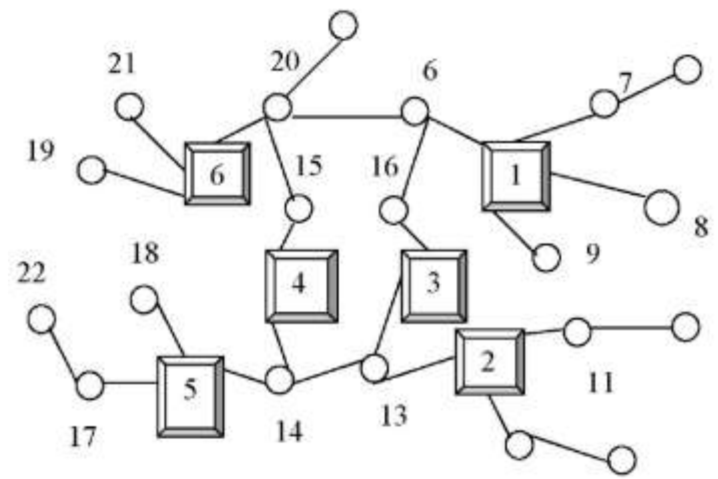
- Packet has target region specified
- Packet Flooding in target region



Recursive Geographic Forwarding in GEAR
(Yu, Govindan and Estrin, 2001)

Max-Min Multi-Hop Routing Protocol (MMMH)

- 1st Phase: Cluster-head nodes construction for backbone network
- 2nd Phase: Construction of optimal paths between nodes
- Inter-cluster topology shared between cluster heads
- Node failure (esp. cluster head) requires rerunning of phases



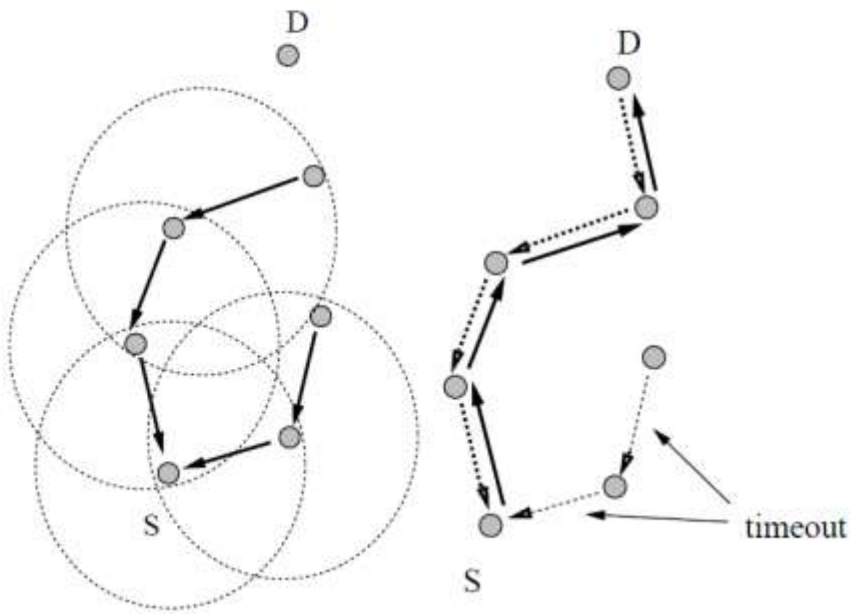
Cluster formation in MMMH
(Pang and Qin, 2006)

Destination-Sequenced Distance Vector Routing (DSDV)

- Ad hoc
- Proactive
- Distance Vector: Routing table maintained by all nodes
- Based on Bellman-Ford (Single-source shortest path)
- No cyclic paths
- Proactive overhead not suitable for highly dynamic networks

Ad hoc On Demand Distance Vector Routing (AODV)

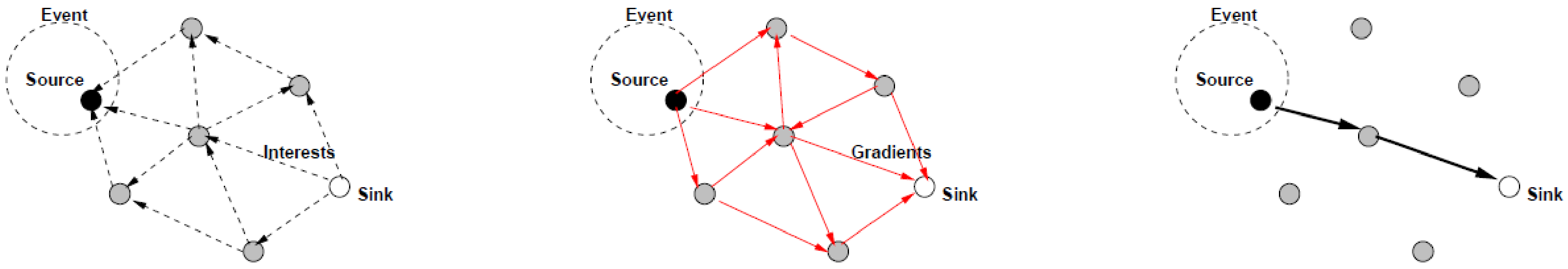
- Ad hoc
- Reactive
- Distance Vector
- No cyclic routes
- Scalable
- Suitable for use with mobile nodes



AODV Reverse Path Formation and Forward Path Formation (Perkins and Royer, 1999)

Directed Diffusion

- Data-centric routing



(a) Interest propagation (b) Initial gradients set up (c) Data delivery along re-inforced path

Directed Diffusion Schematic (Silva et al., 2004)

Directed Diffusion

protocol	sink	source
two-phase pull	interest* (every interest interval)	
		exploratory data* (every exploratory interval)
	positive reinforcement (response to exp. data)	
		data (rate defined by app.)
one-phase pull	interest* (every interest interval)	
		data
push		exploratory data* (every exploratory interval)
	positive reinforcement (response to exp. data)	
		data

Directed Diffusion Variants (Silva et al., 2004)

References

8) C. E. Perkins and E. M. Royer. Ad-hoc on-demand distance vector routing. In *Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA '99. Second IEEE Workshop on*, pages 90-100, 1999.
9) Kong L. Pang and Yang Qin. The comparison study of flat routing and hierarchical routing in ad hoc wireless networks. In *Networks, 2006. ICON '06. 14th IEEE International Conference on, title=The Comparison Study of Flat Routing and Hierarchical Routing in Ad Hoc Wireless Networks*, pages 1-6, September 2006.
10) Yan Yu, Ramesh Govindan, and Deborah Estrin. Geographical and energy aware routing: a recursive data dissemination protocol for wireless sensor networks, 2001.
11) Kemal Akkaya and Mohamed Younis. A survey on routing protocols for wireless sensor networks. *Ad Hoc Networks*, 3:325-349, 2005.