DMC

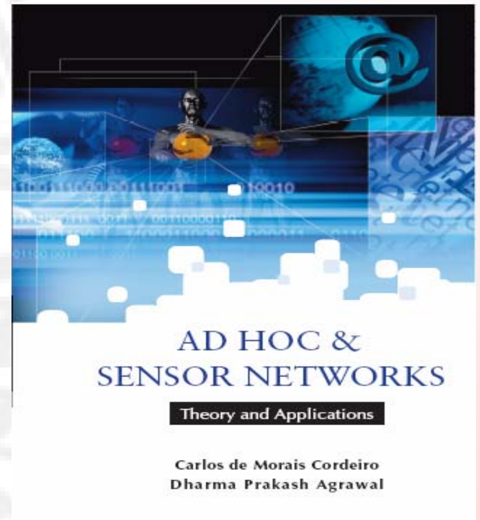
Future Directions in Wireless and Mobile Systems

Dr. Dharma P. Agrawal
Ohio Board of Regents Distinguished Professor
Center for Distributed and Mobile Computing
Department of Computer Science
University of Cincinnati, Cincinnati, OH, 45221-0030
Tel:513-556-4756 E-mail:dpa@cs.uc.edu,
Web: http://www.cs.uc.edu/~dpa

A Brief History of CDMC

- Founded by Dr. Agrawal in August 1998
- Graduated 25 PhDs and 35 MSs in last 10 years
- No. of graduates: 55 PhDs and 38 MSs
- Current Strength
  - 15 PhD and 11 MS students
  - Several International visitors
  - Publications during years 2004-2008:
  - Journal Publications: 52
  - Magazines: 5
  - Conferences: 112
  - Invention disclosures: 9
  - Books: 2
  - Book Chapters: 16
  - Editorial board of four new journals in Ad hoc/Sensor Networking

http://www.worlscibooks.com/engineering/6044.html



Edited book: 2009

Encyclopedia on Ad Hoc and Ubiquitous Computing

World Scientific Press

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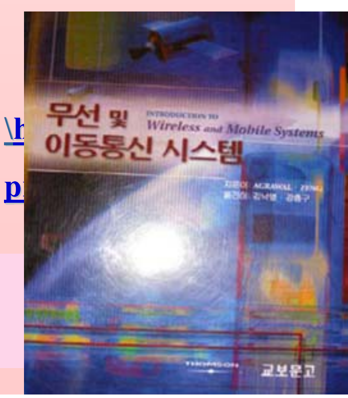

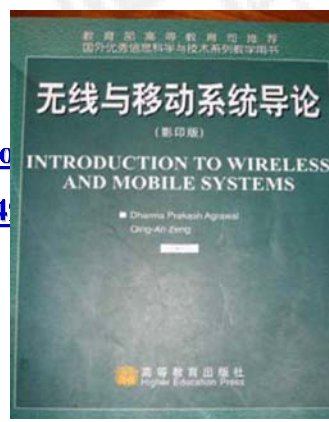

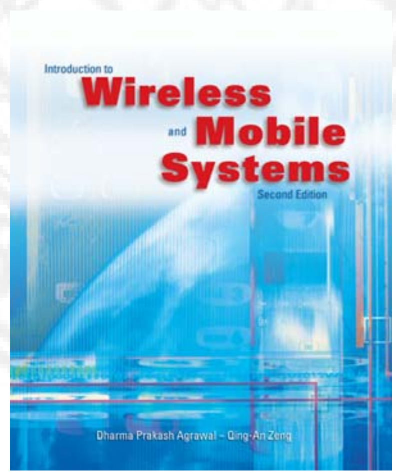

Recent Graduates from Cincinnati?

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25 PhDs and 35 MSs

Qualcomm Incorporated
SACHIN ABHYANKAR
DISHA AHUJA
SAGAR DHARIA
RANGANATH DUGGIRALA
MEETU GUPTA
ANAND KUMAR
MADATHILL DILIP KUTTY
KARTIKA PALADUGU
DAMANJIT SINGH
XIAODONG WANG (PhD)

Microsoft Research
TARUN JOSHI (PhD)
QI ZHANG (PhD)

France Telecom R&D
RASHMI BAJAJ

Bosch R&D Center
VIVEK JAIN (PhD)
ARATI MANJESHWAR
LAKSHMI VENKATRAMAN

Google
RATNABALI BISWAS (PhD)
ANURAG GUPTA (PhD)
ANINDO MUKHERJEE (PhD)
JING-AO WANG

Ericsson
PREMKUMAR KRISHNAN

Cornell University, MBA Candidate
ROY L. ASHOK

Motorola
YUNLI CHEN (PhD)
SAGAR DHARIA
HRISHIKESH GOSSAIN (PhD)
RAHUL GUPTA
WEI LI (PhD)
ABINASH MAHAPATRA
NAGESH NANDIRAJU (PhD)
VIVEK SHAH
ANURAG SHARMA
HAITANG WANG (PhD)
QIHE WANG (PhD)

nVIDIA
TORSHA BANERJEE (PhD)

Intel Corp.
CARLOS D. M. CORDEIRO (PhD)
LAKSHMI SANTHANAM (PhD)

Philips Research
DAVE CAVALCANTI (PhD)

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Recent Graduates from Cincinnati?

OPNET Technologies
RAVIKIRAN KAKARAPARTHI

Alcatel
SIDDESH KAMAT

Cisco
RAMNATH DUGGIRALA

i-a-i
HONGMEI DENG (PhD)
YI CHENG (PhD)

U Tube
SHRUTI CHUGH

Convergys
SANDHYA SEKHAR
SASHIDHAR VOGETY

New Graduate
SUMON BANERJEE

Georgia Tech
KAUSHIK CHOWDHURY

Epic Systems
RISHI TOSHNIWAL

Southern Ilinois University
JUN WANG (PhD)

Eaton Corp.
DHANANJAY LAL (PhD)

Delta Dental Plan of MI
ABISHEK JAIN

Crossbow
NEHA JAIN (PhD)

Deloitte & Touche
ANANYA GUPTA

Quincy University
NITIN AULUCK (PhD)

Midland Company
RAJANI POOSARLA

Logic Systems
SAMANTHA RANAWEERA

Convergys
SANDHYA SEKHAR

Interthinx
ADITYA GUPTA

Johnson Smith University
HANG CHEN (PhD)

Dominican University
JUN YIN (PhD)

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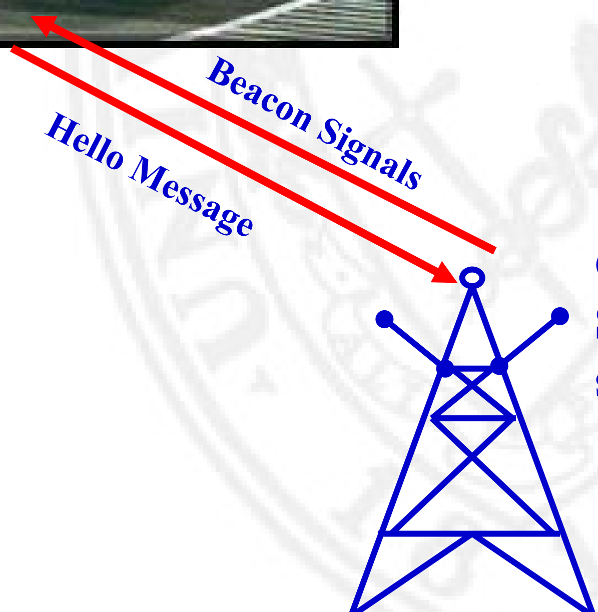
Center for Distributed and Mobile Computing

Presentation Outline

- What Is A Wireless Cellular/Mobile Network?
- How Does It Work?
- What About Ad hoc and Sensor Networks?
- Recent Result Results in Wireless and Mobile Networks by our group?
- Future Directions?

Cell (Mobile) Phone

As soon as the airplane's door is opened, you can switch on the cell phone and you are connected….



Cell Phone contacts the nearest Base Station and registers itself to get service.

Cellular Service Base Station

What is a cell?

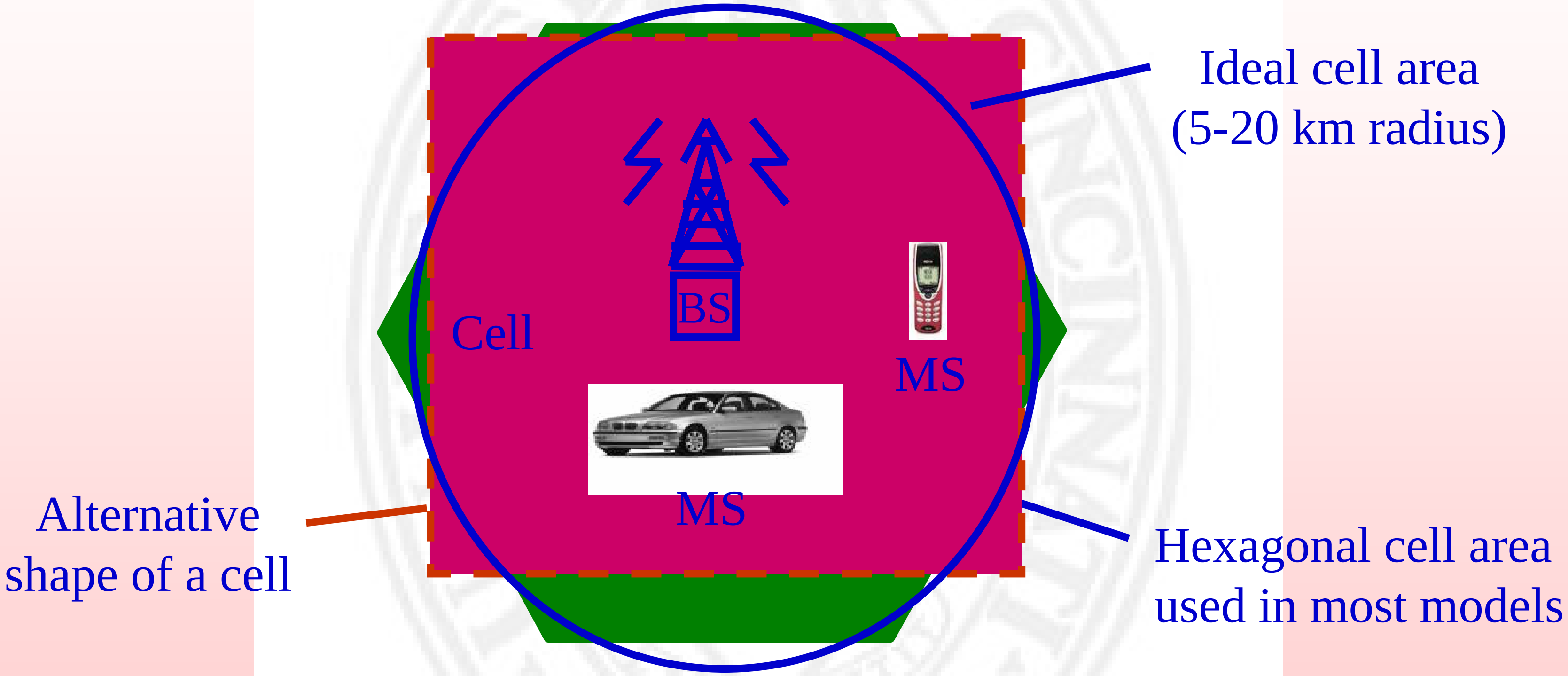
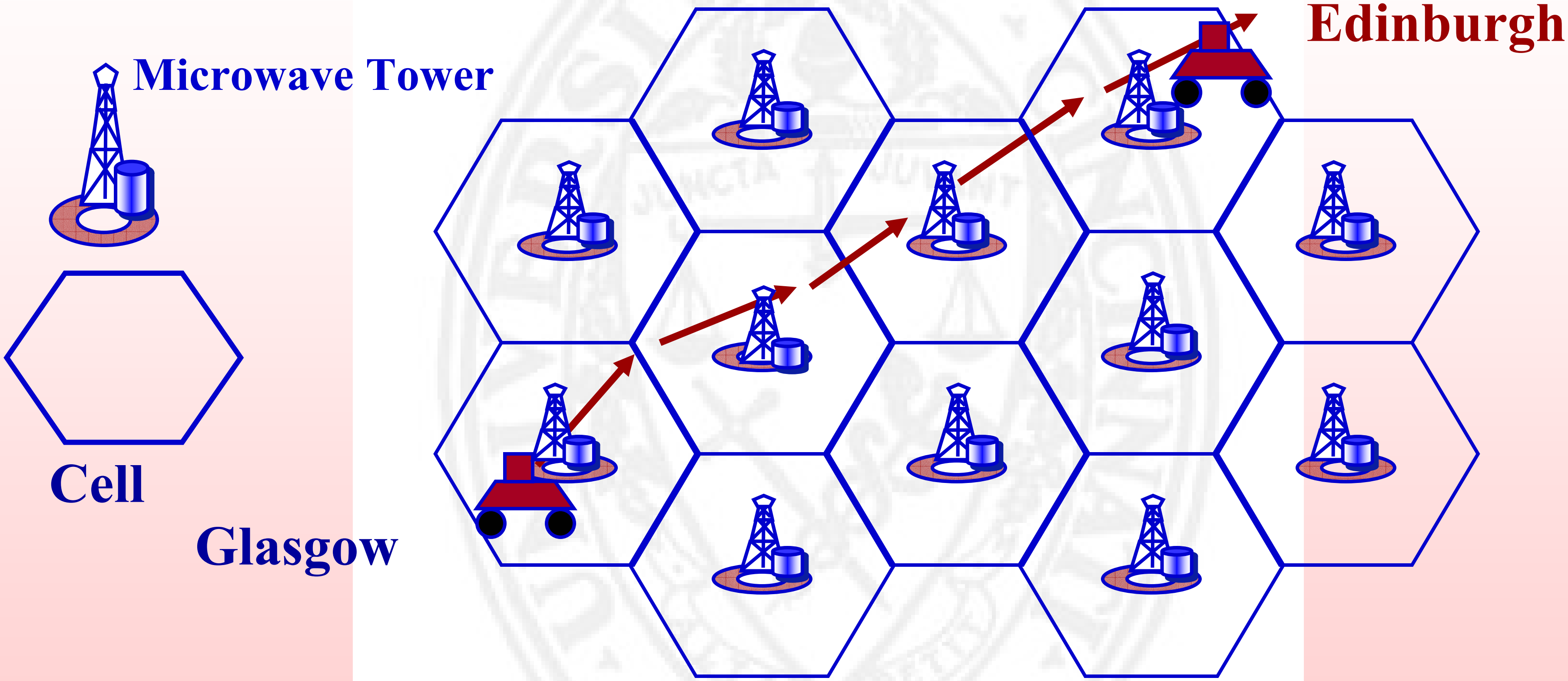


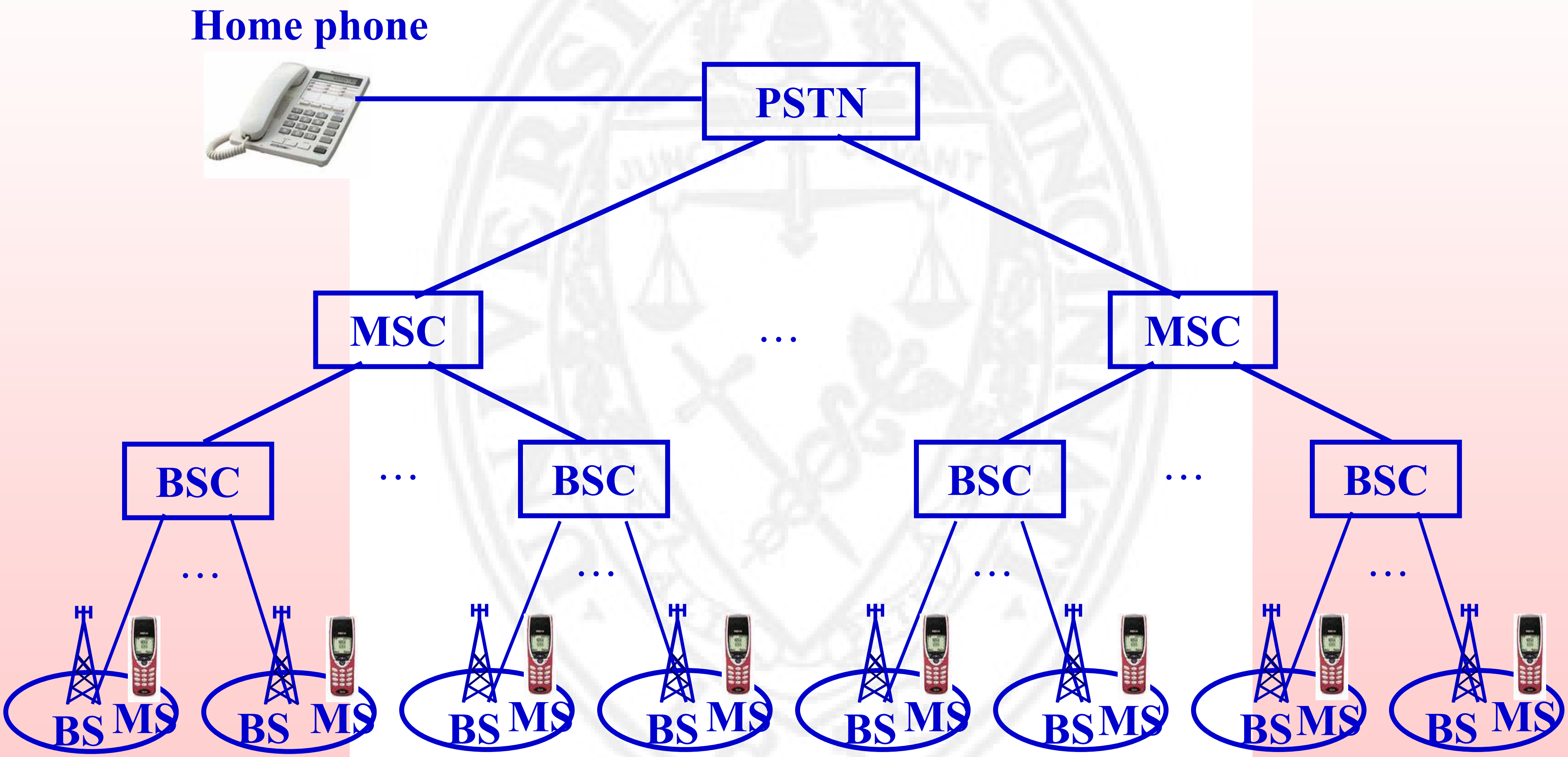
Illustration of a cell with a mobile station and a base station

Universal Cell Phone Coverage

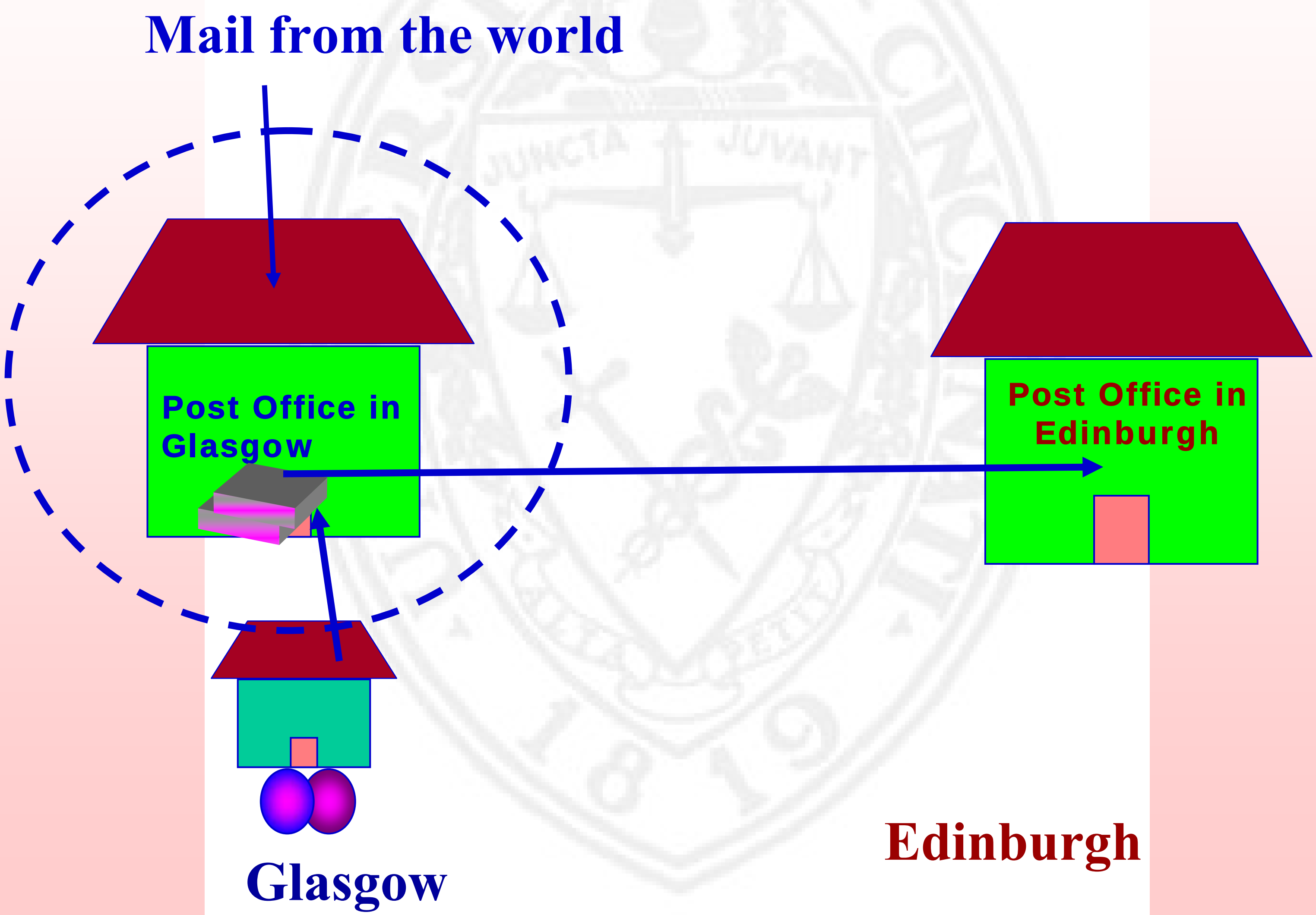


Maintaining the telephone number across geographical areas in a wireless and mobile system

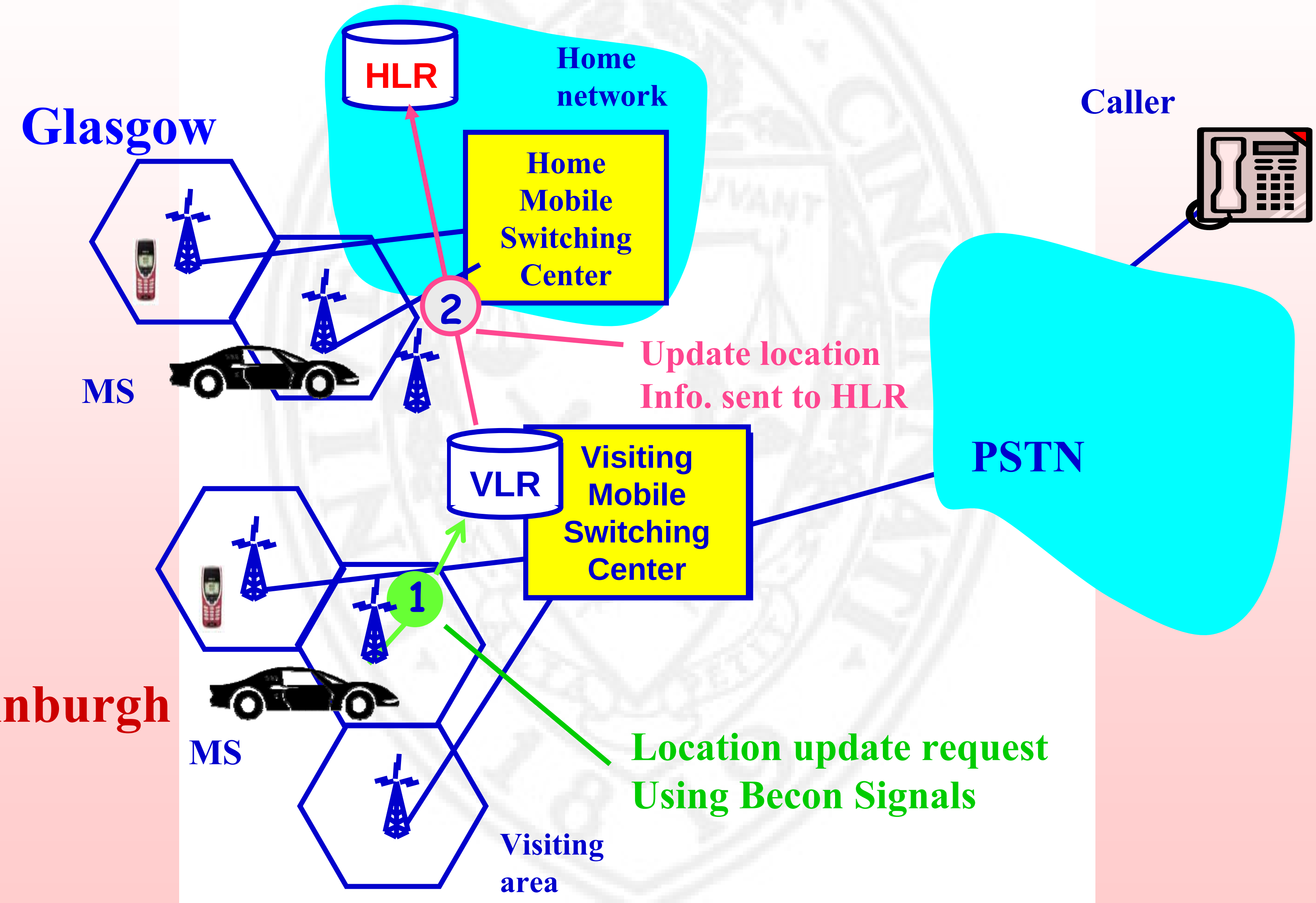
Essential functional components of a Cellular Infrastructure



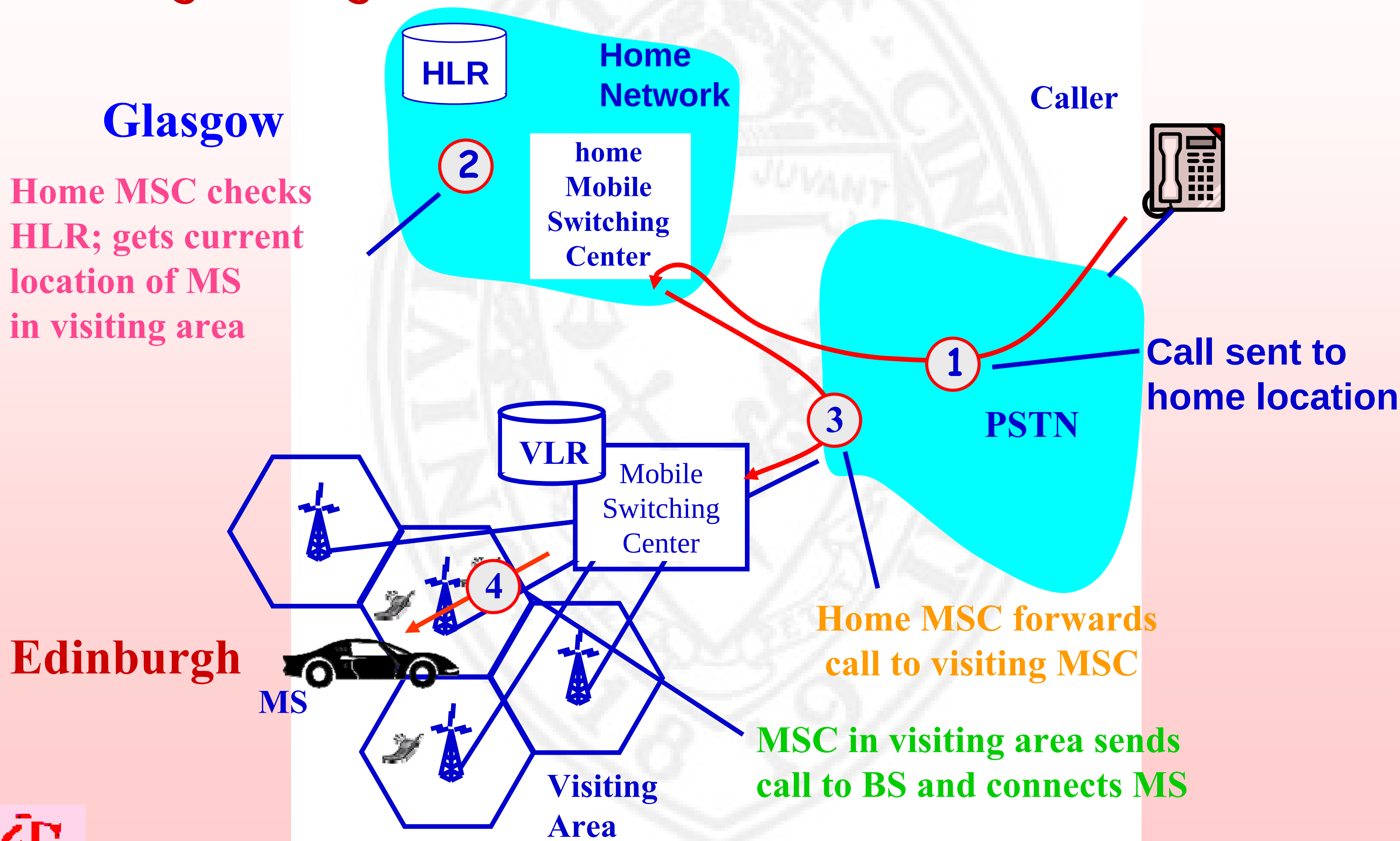
Classical Mail Forwarding Technique?



Automatic Location Update



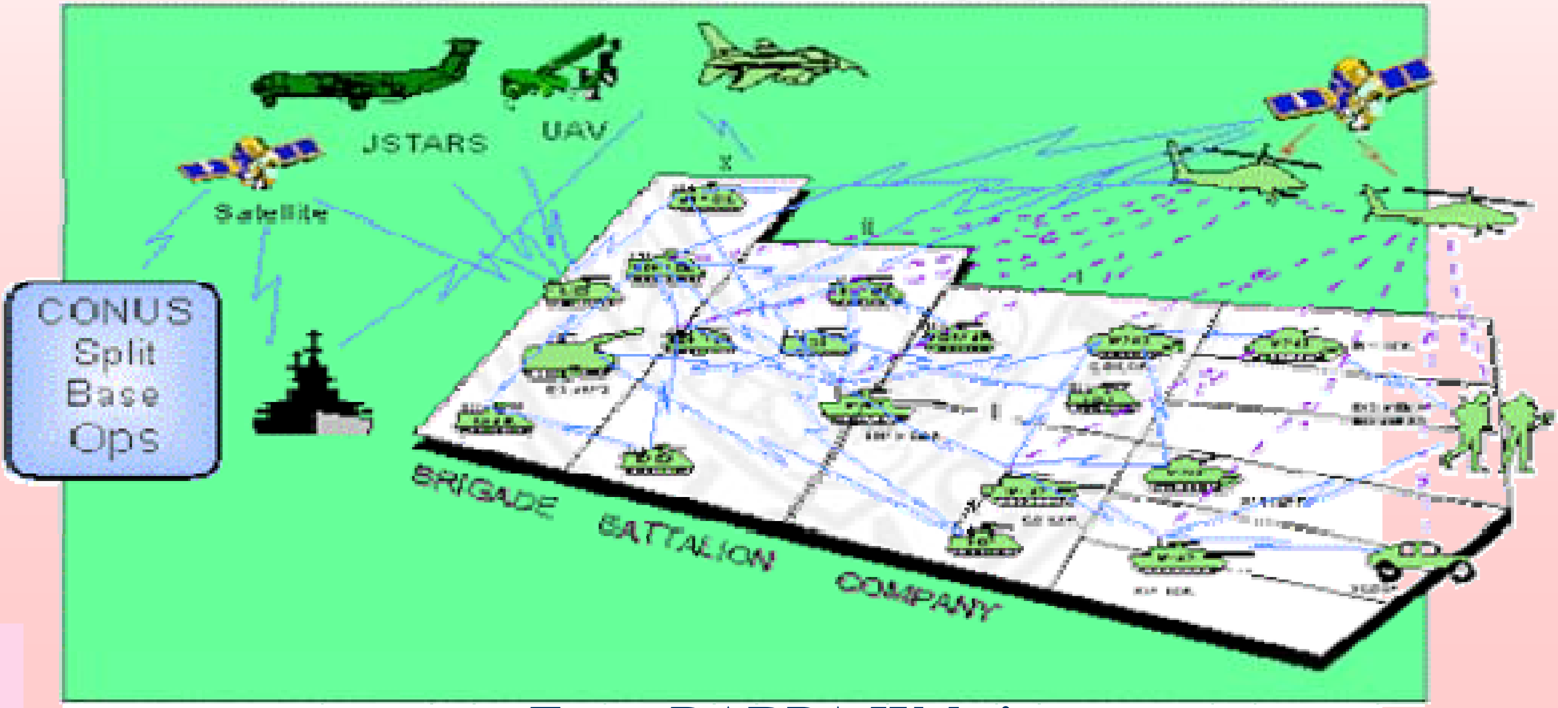
Automatic Call Forwarding using HLR-VLR



MANETs: Mobile Ad hoc Networks

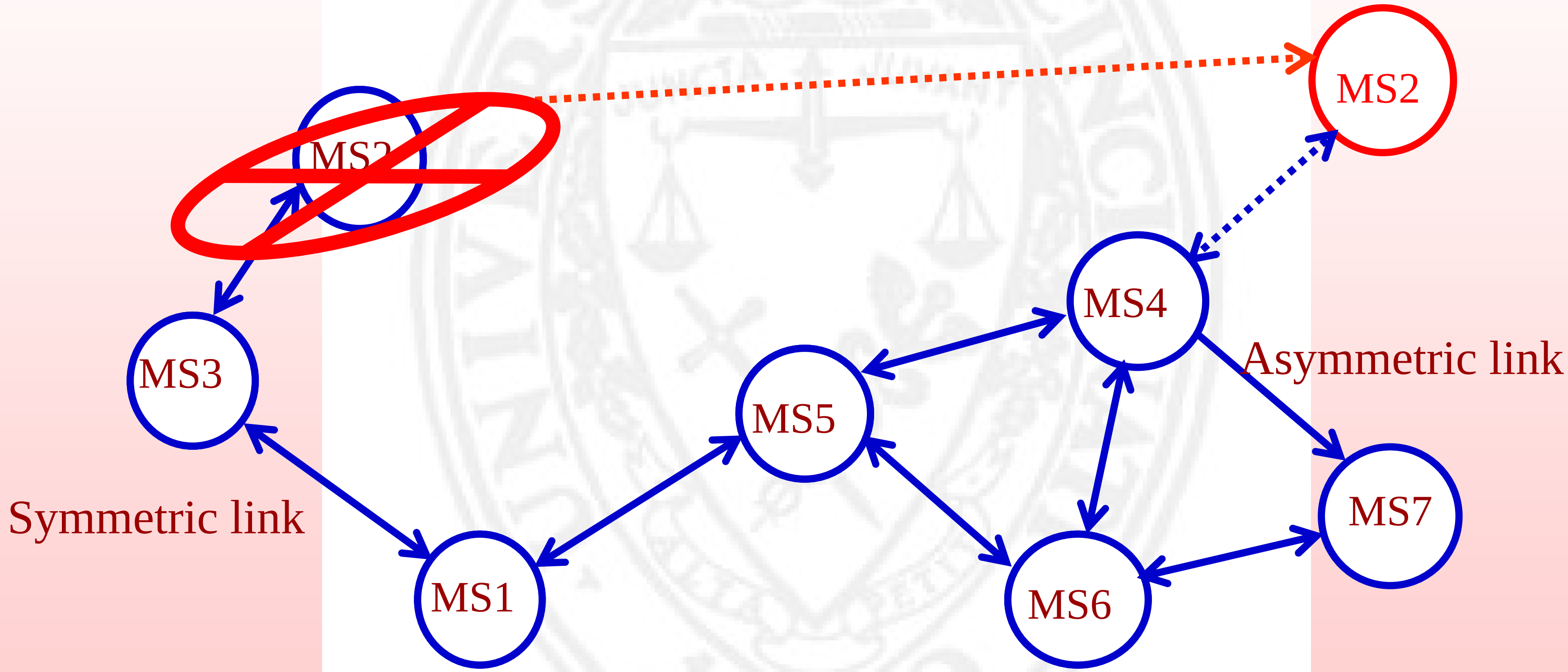
Collection of wireless mobile nodes dynamically forming a network without any existing infrastructure and dynamically changing communication links, totally distributed network due to geographical or terrestrial constraints

Applications: **Military applications (battlefield), disaster situations, etc.**



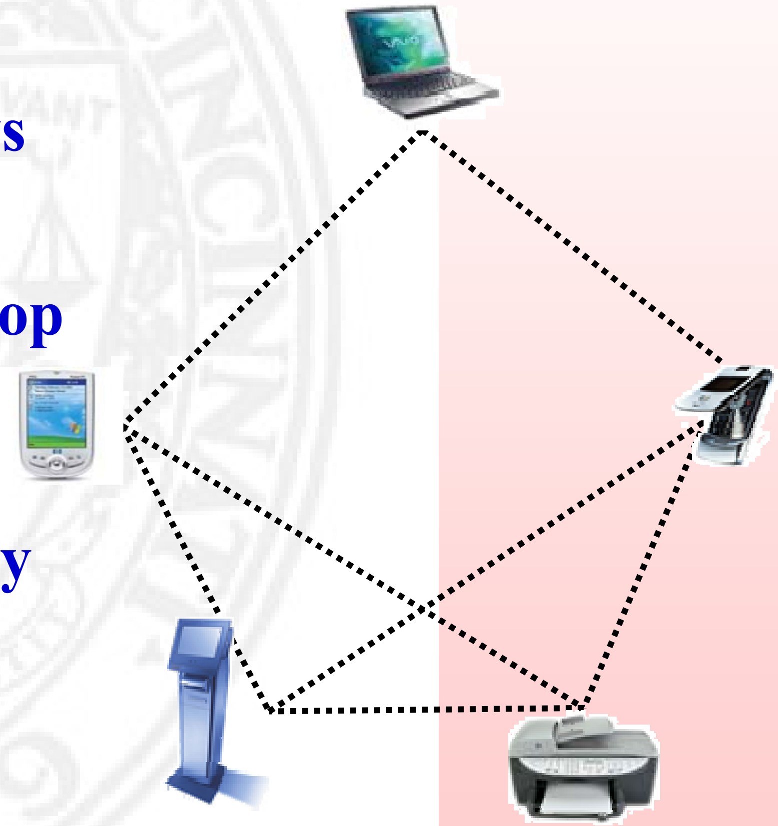
From DARPA Website

A Mobile Ad Hoc Network (MANET)



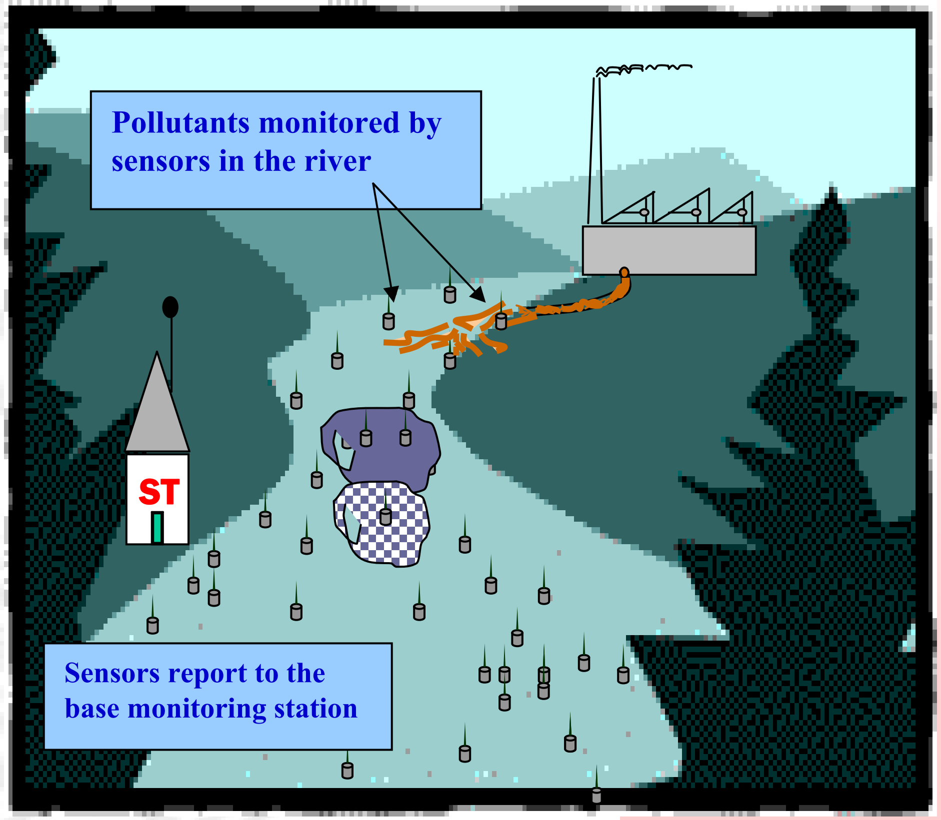
Mobile Ad Hoc Networks (MANETs) Characteristics:

- An autonomous system of nodes (MSs) connected by wireless links
- Lack of fixed infrastructure relays
- Absence of centralized authority
- Peer-to-peer connectivity Multi-hop forwarding to ensure network connectivity
- Topology may change dynamically
- Random Multi-hop Graph
- Energy-constrained
- Bandwidth-constrained, variable capacity links



Example of a Sensor Network to monitor the Environment

- Measuring pollutant concentration
- Pass on information to monitoring station
- Predict current location of pollutant contour based on various parameters
- Take corrective action



What is a Sensor Network?

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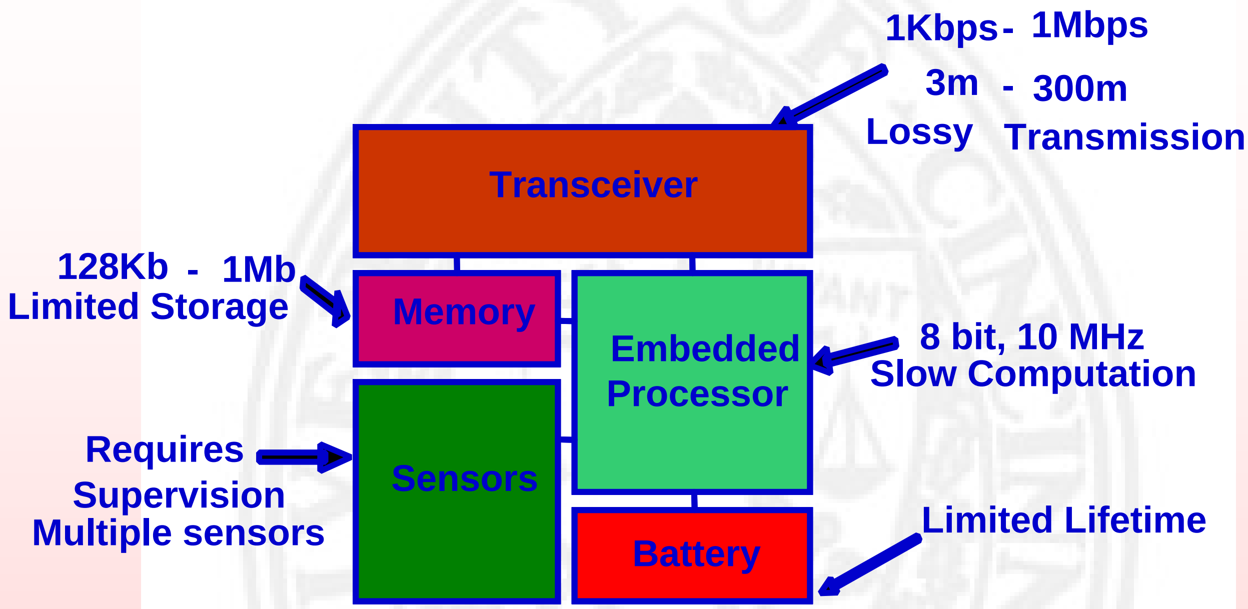
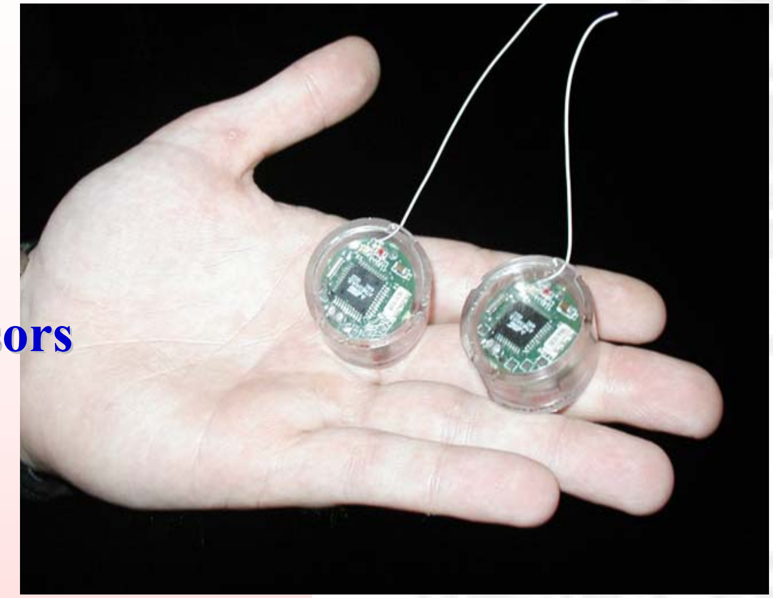


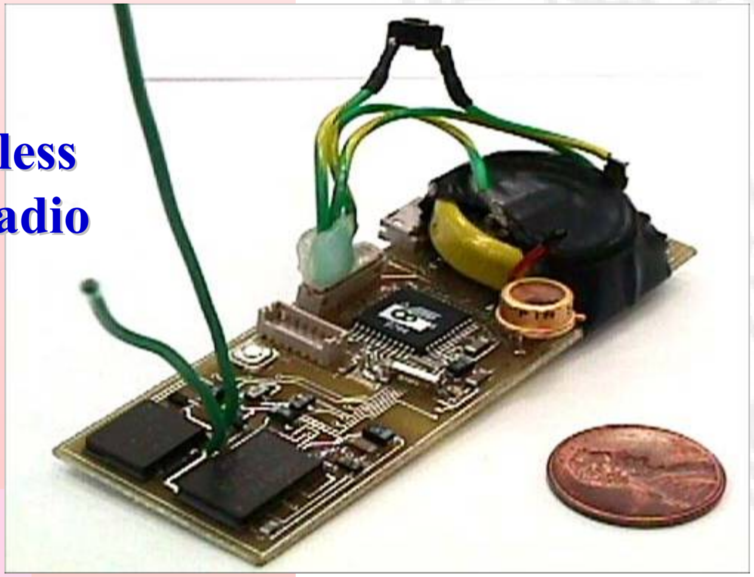
- Portable and self-sustained (power, communication, intelligence)
- Equipped with multiple sensing, programmable computing and communication capability
- Note: Power consumed in transmitting 1Kb data over 100m is equivalent to 30M Instructions on 10MIPS processor

Sensors and Wireless Radio

Sensors



Wireless Radio



- Types of sensors:
  - -Pressure
  - -Temperature
  - -Light
  - -Biological
  - -Chemical
  - -Strain, fatigue
  - -Tilt

- Capable of surviving harsh environments (heat, humidity, corrosion, pollution, radiation)
- Could be deployed in large numbers

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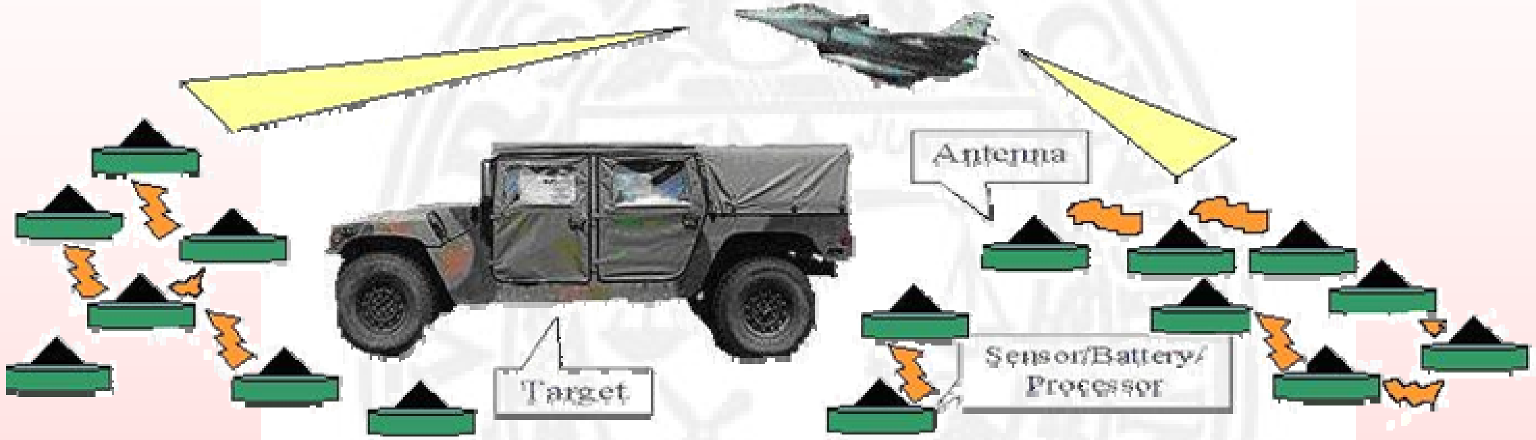
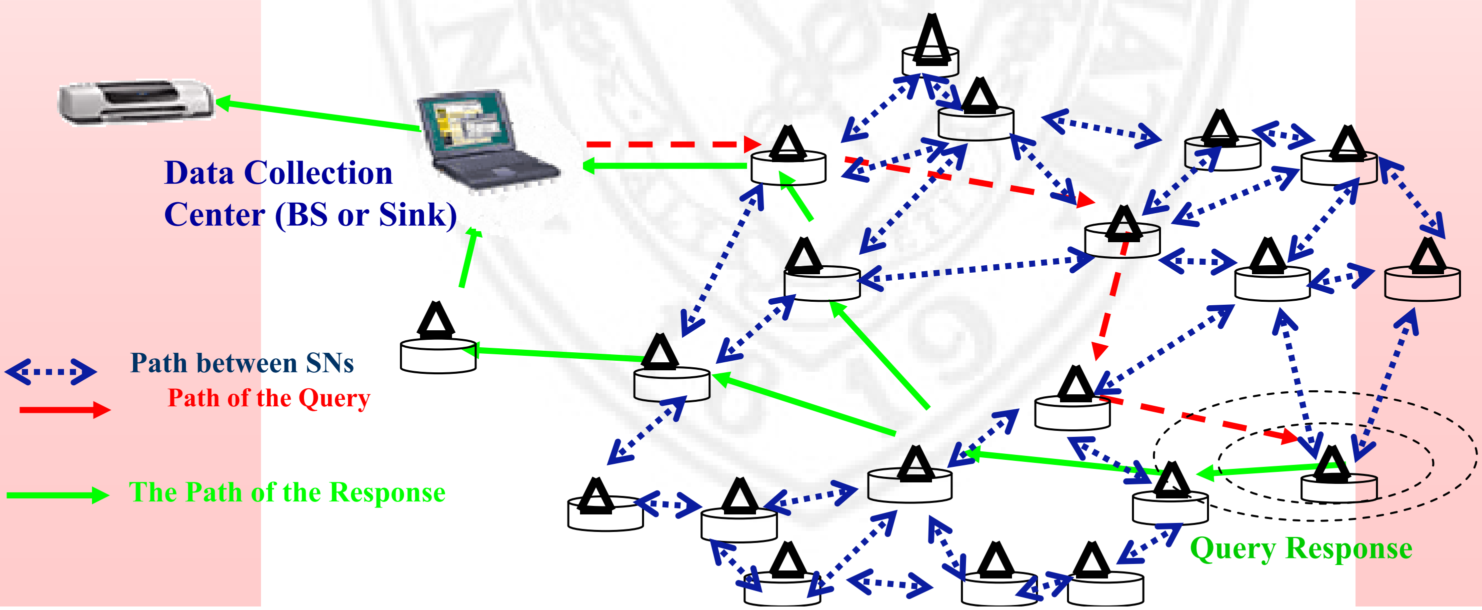
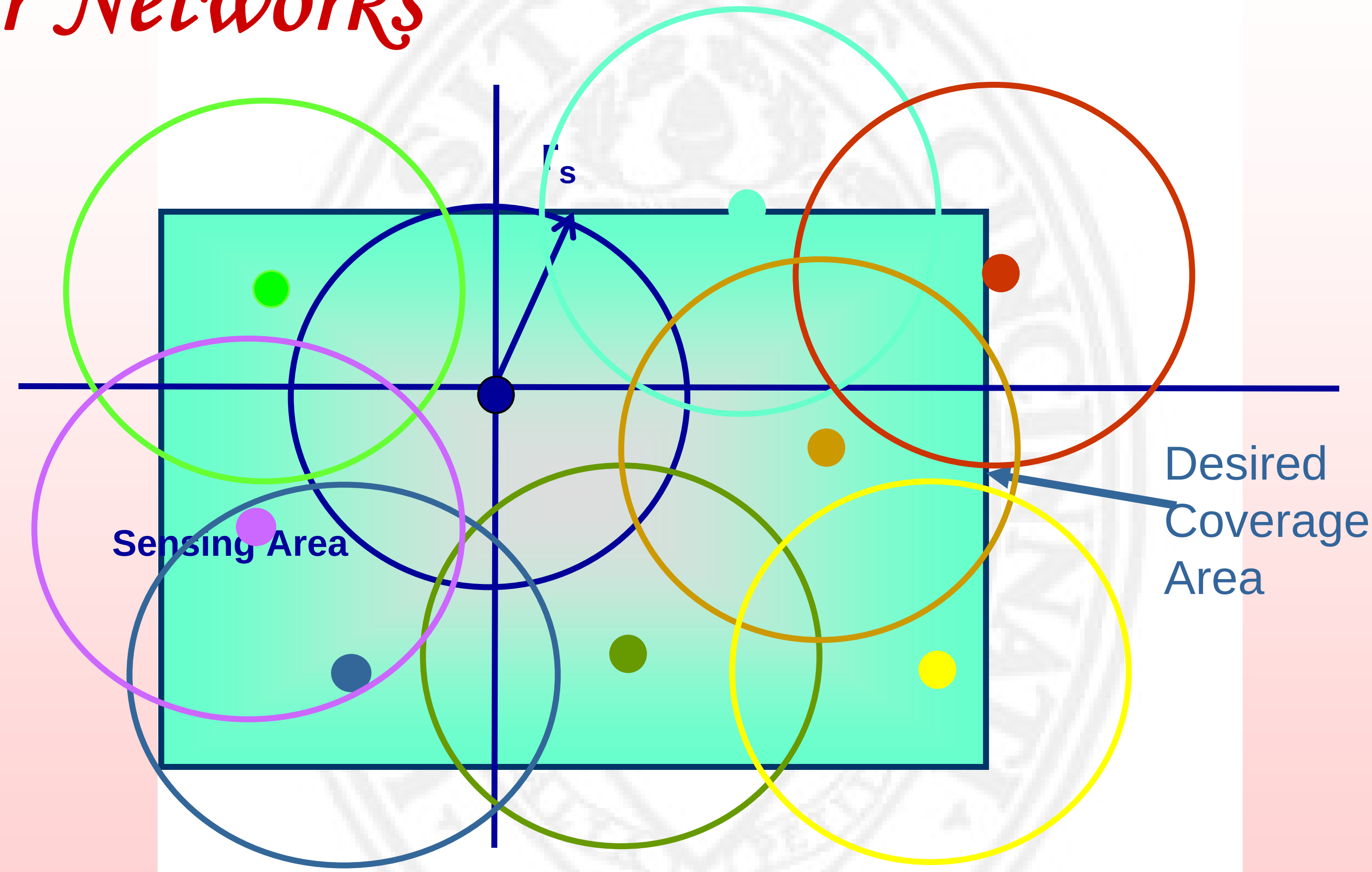
Application of Wireless Sensor Networks in Defense Applications



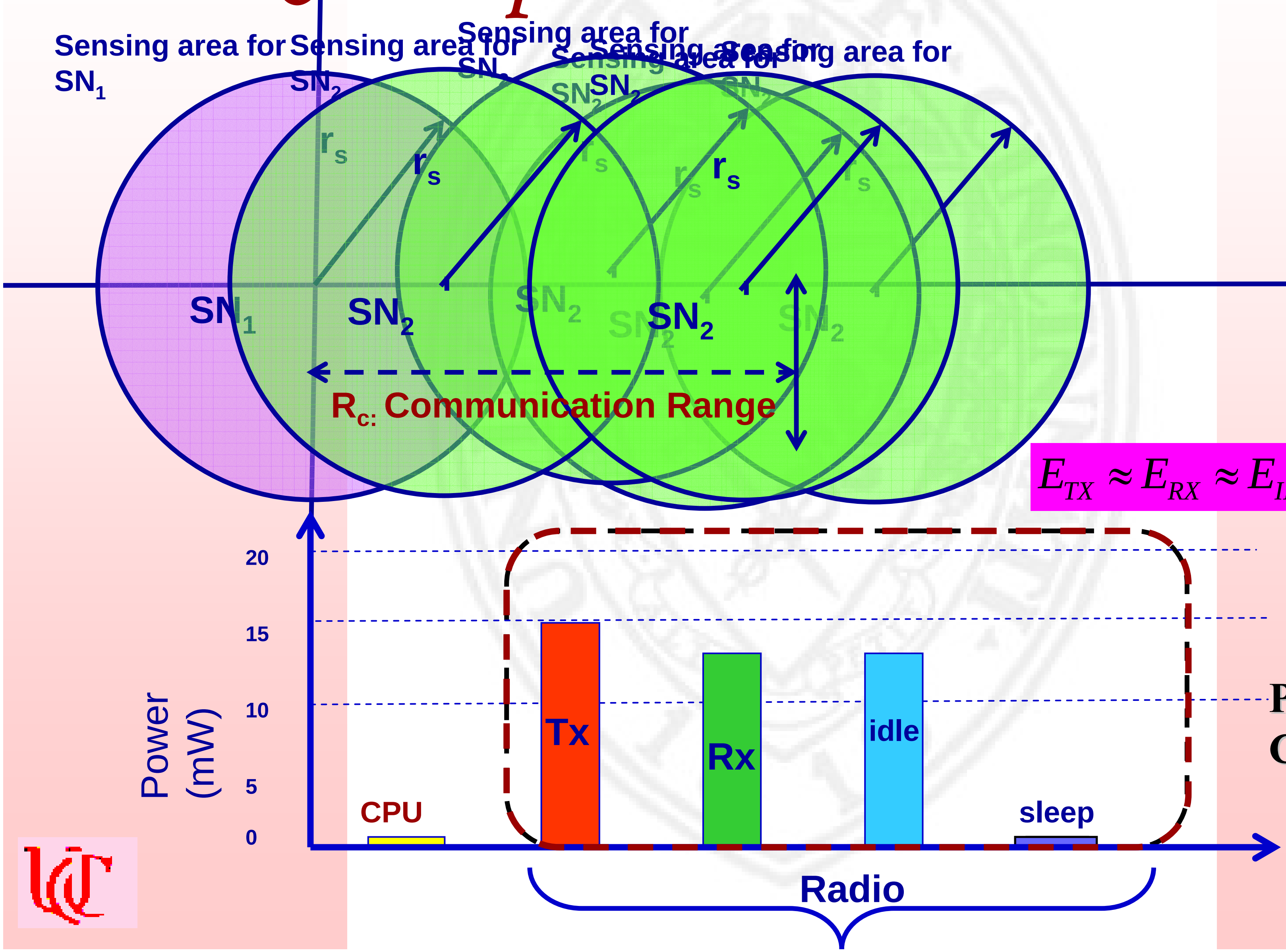


Coverage and Reachability in Wireless Sensor Networks



- There exist fundamental limits in the operation of WSN:Low date rate, Sheer network size, limited computing power, communication range and battery capacity
- Example: If some types of sensor nodes is given, how to choose number of each type of sensors to achieve the requirement that 80% of nodes should be 1-covered and connected together?

Sensing/Communication Range & Power Consumption

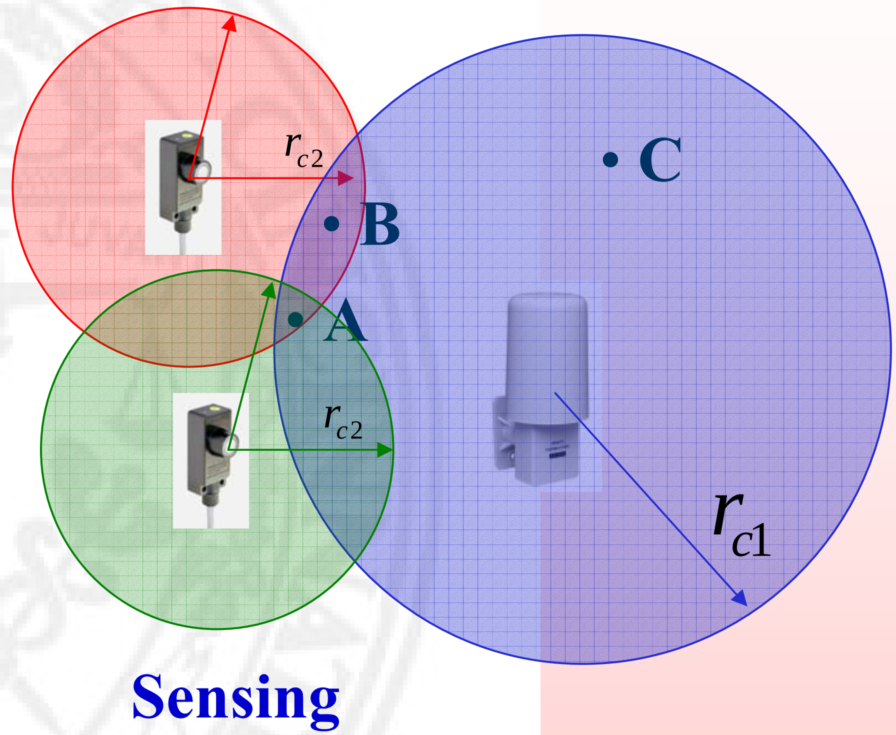


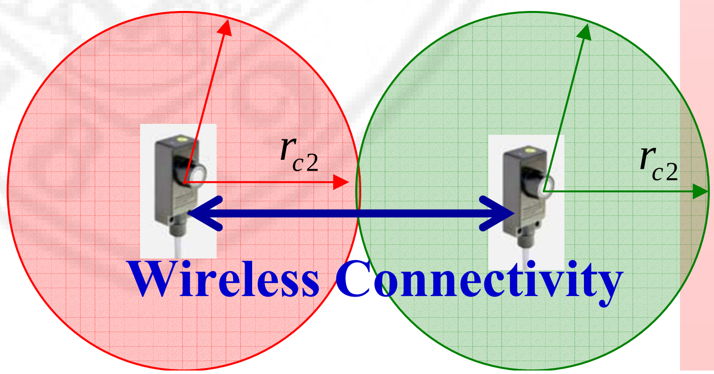
$$E_{TX} \approx E_{RX} \approx E_{IDLE} >> E_{SLEEP}$$

Power Consumption

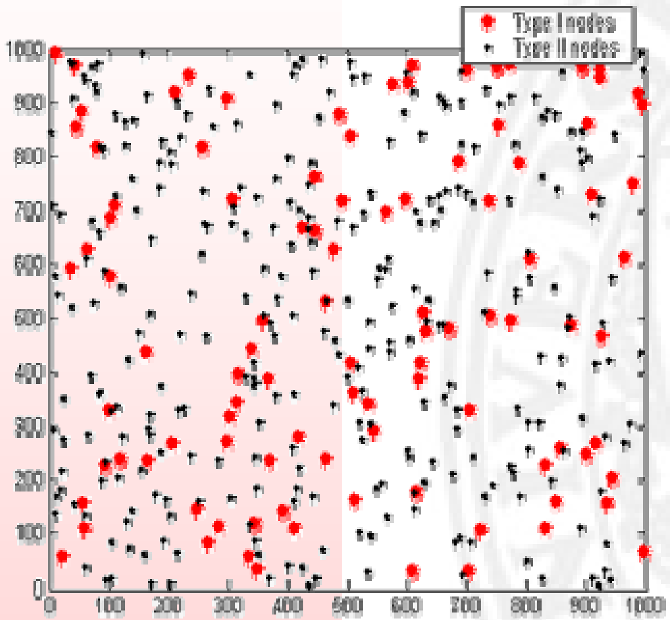
K-Coverage and Connectivity in Heterogeneous WSN

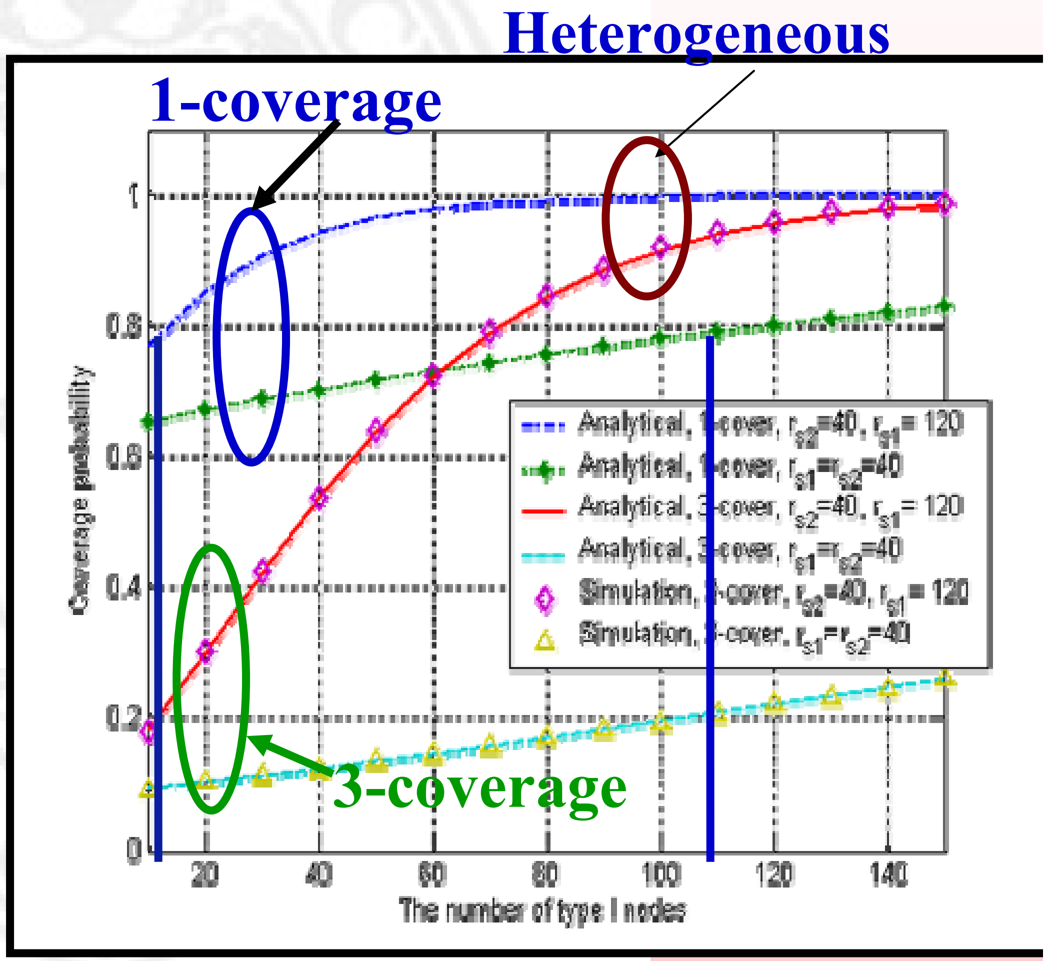
- **K-cover probability is defined as the probability that there are at least *k* nearby sensor nodes which can sense it**
- **These *k* nearby sensors can be any combination of Type I and Type II nodes**
- **Wireless Connectivity?**





Impact of Adding Powerful Sensors in HWSN by Analysis and Simulation





Two types of sensors

N_1 = 100 N_2 = 300 L =1000m

Coverage Prob. vs. # of Type 1 Nodes

Data Aggregation in a Sensor Network

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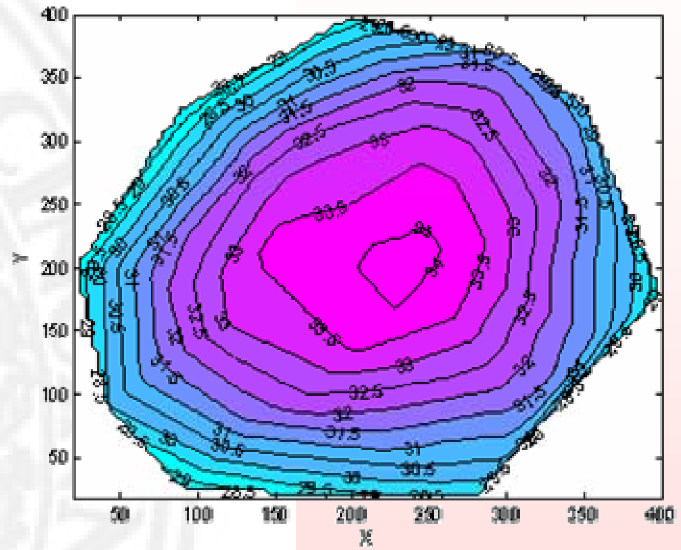
- Each sub-region has a data aggregation tree
  - Tree nodes aggregate data from non tree nodes
- The values stored at each tree node can be considered as function values having x-y inputs
- A polynomial equation
- p(x,y)= $\beta_0 + \beta_1 y + \beta_2 y^2 + \beta_3 x + \beta_4 x\, y + \beta_5 x y^2 + \beta_6 x^2 + \beta_7 x^2 y + \beta_8 x^2 y^2$
  is generated through function approximation with three input variables (z, x, y) where f_m is the attribute value sensed at (x, y)
- Correlation between sensed attribute (temperature for eg. with values between 30^o-34^o) and coordinates of sensing node reporting to each tree node
- Substituting (x, y) value in the range $\{x_{min,} y_{min}, x_{max}, y_{max}\}$ gives the approximated attribute value at that location



Sensed Temperature Contour

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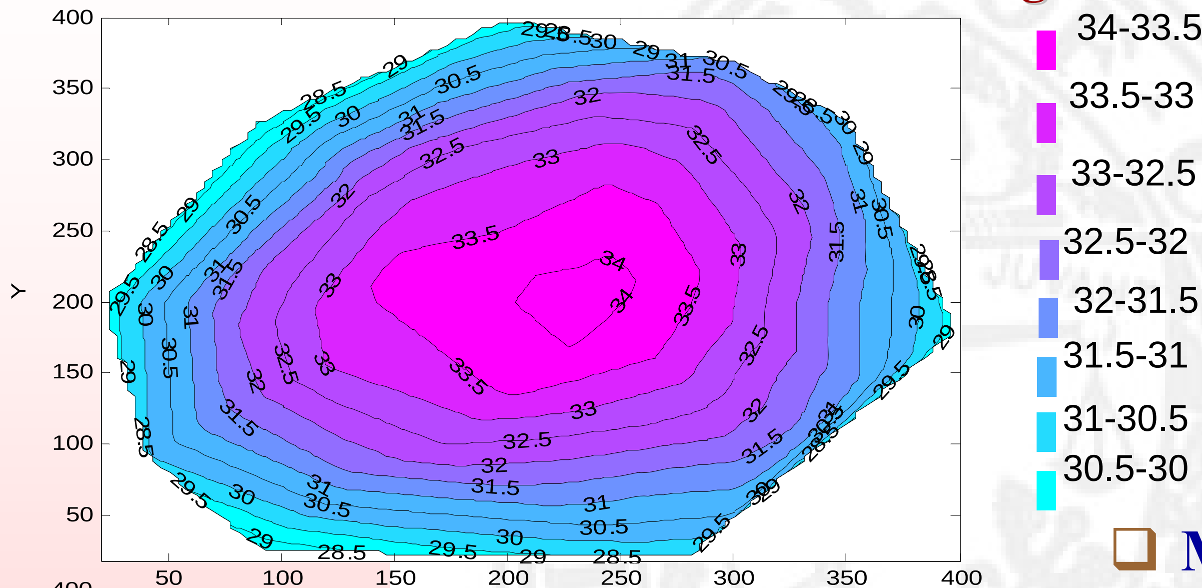
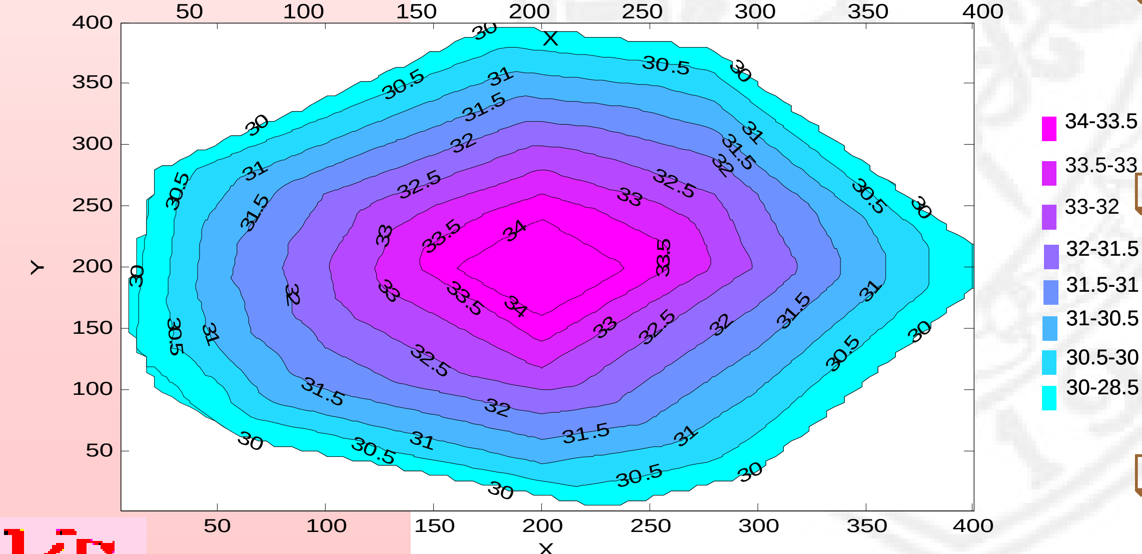
Performance Evaluation

Original Data



Parameters used	
Total Area A_N	800*800
Area Sensed A_s	400*400
# sensors N	1630
Sensing Range R_s	40m
$\rho = R_s / N$	0.0245
Quad tree depth	4
# sensors reporting to a tree node	12

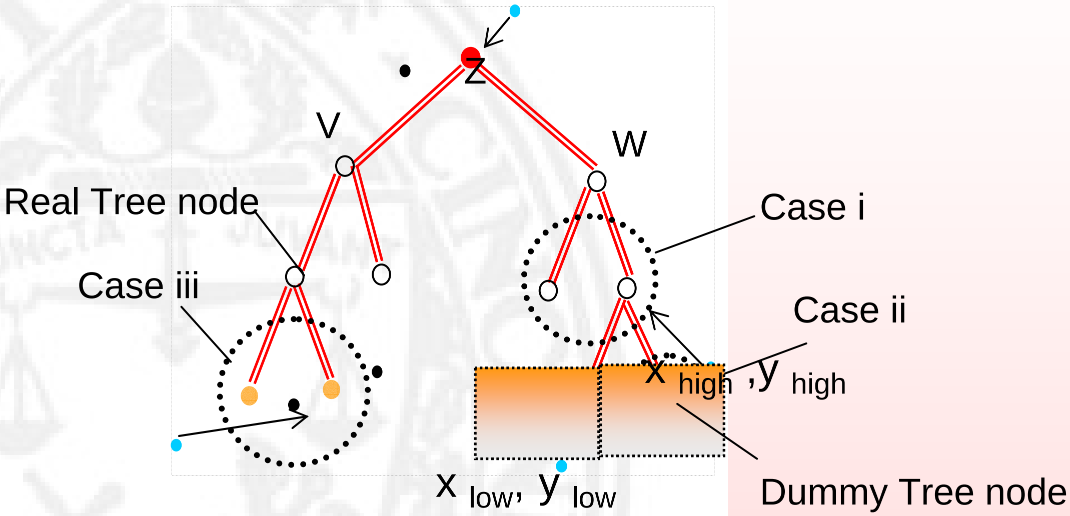


Synthetic model depicts the correlation between with approximated attribute values and coordinates of NT nodes

- **Maximum error of 5.64%, with tree of depth 4 (mostly 0-1.68% range)**
- **Compression ratio of 50% obtained independent of depth of aggregation tree**
- **Fixed data packet size is gives substantial energy savings**

If a Sensor not present, use Dummy

- **Binary QT might not be complete**
- **Non-leaf node can have less than one child**
- **Nodes can be out of range of each other after random deployment**

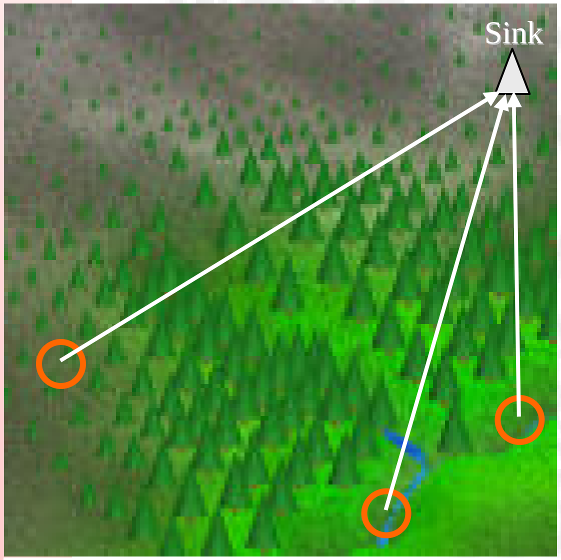


Sensors not present

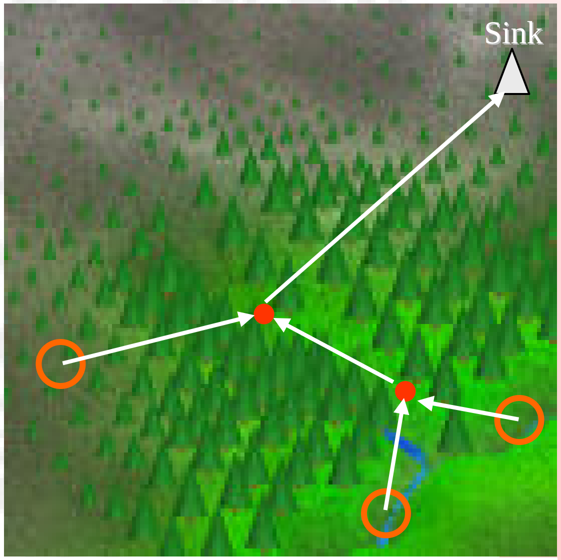
Readings from neighboring nodes are very similar
Neighboring aggregating nodes approximate the values of the nonexistent nodes
3 cases may occur
(i) Both children are present
(ii) Only one child is present
(iii) No child is present

Energy Aware Retrieval for many Regions of a Sensor Network

- **Long running queries to monitor events occurring in several target regions geographically separated from each other**
- **Communication Architecture to support continuous in-network query processing**
- **Query Processors: Heterogeneity?**

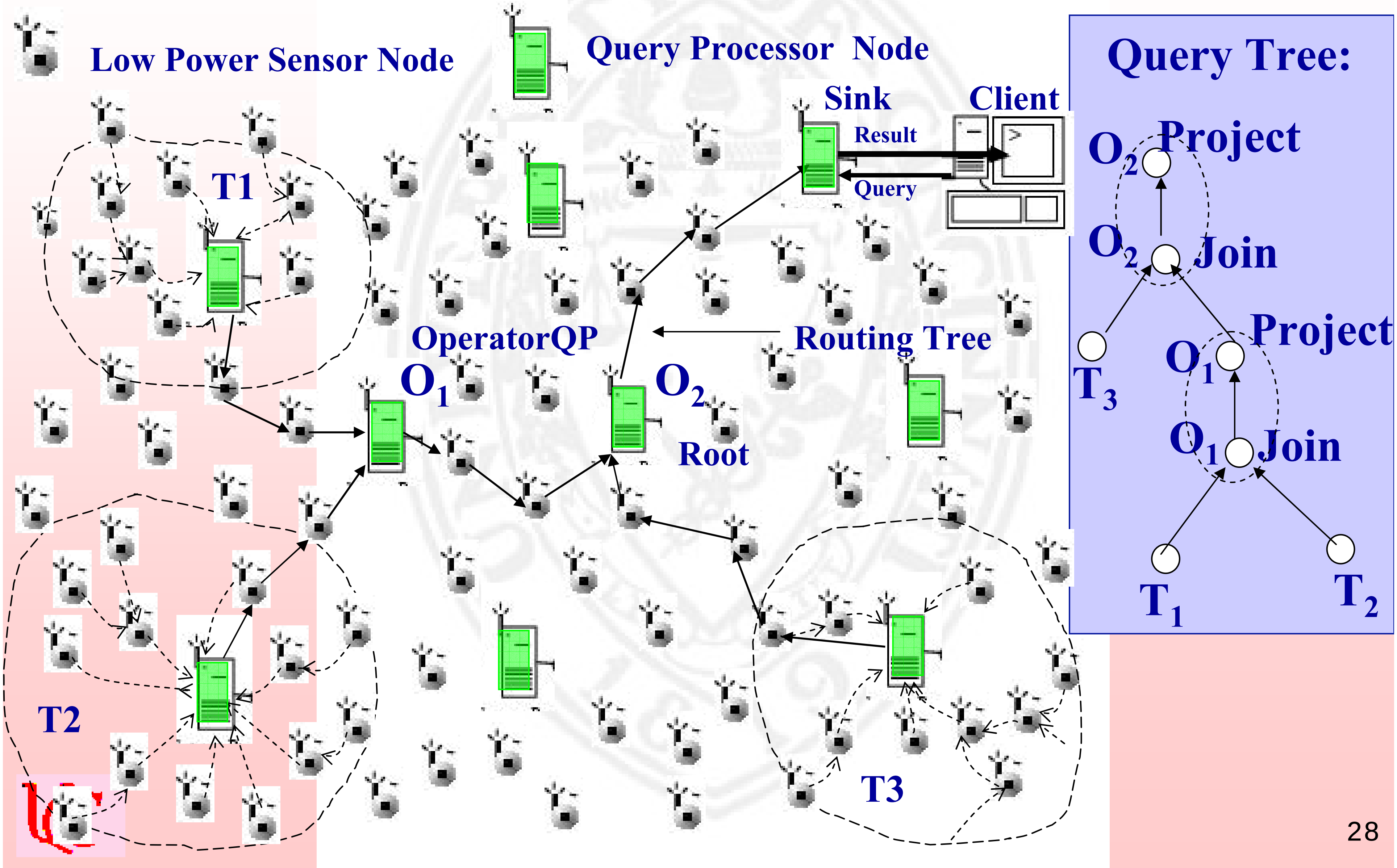


Conventional Scheme: External Storage and Processing



In-network Processing desirable

Mapping Query tree to Routing tree



Communication Architecture

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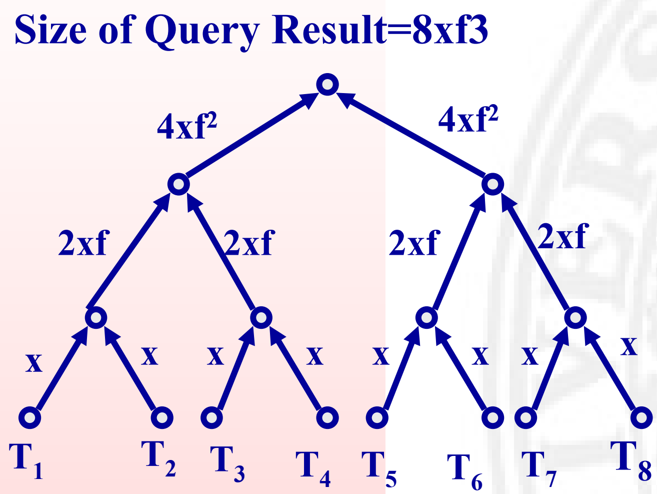


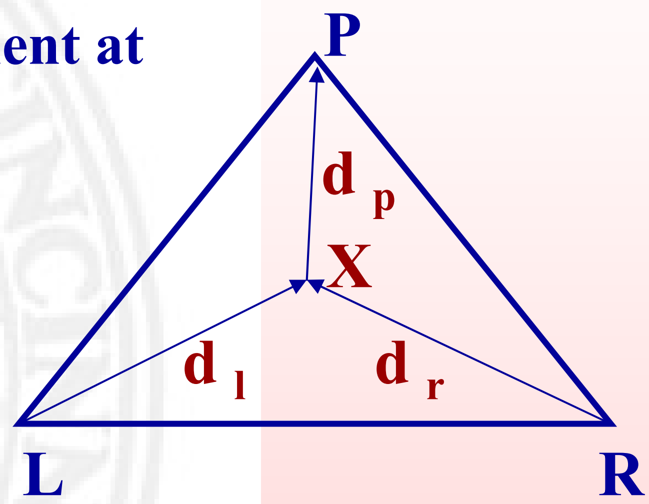
(Data Reduction at each operator is f)

Binary Query Tree on values received from different regions

- Heterogeneous System:
  - Query Processor (QP nodes): Computation Intensive data processing, (Join, Aggregation)
  - Low Power Sensor Nodes: Sensing, Routing, Simple Computations (e.g., Berkeley Mica motes)
- Motivation: Reduce traffic in the network
- Minimize distance traversed by data traffic to take advantage of in-network processing
- Where to place Query Operator?

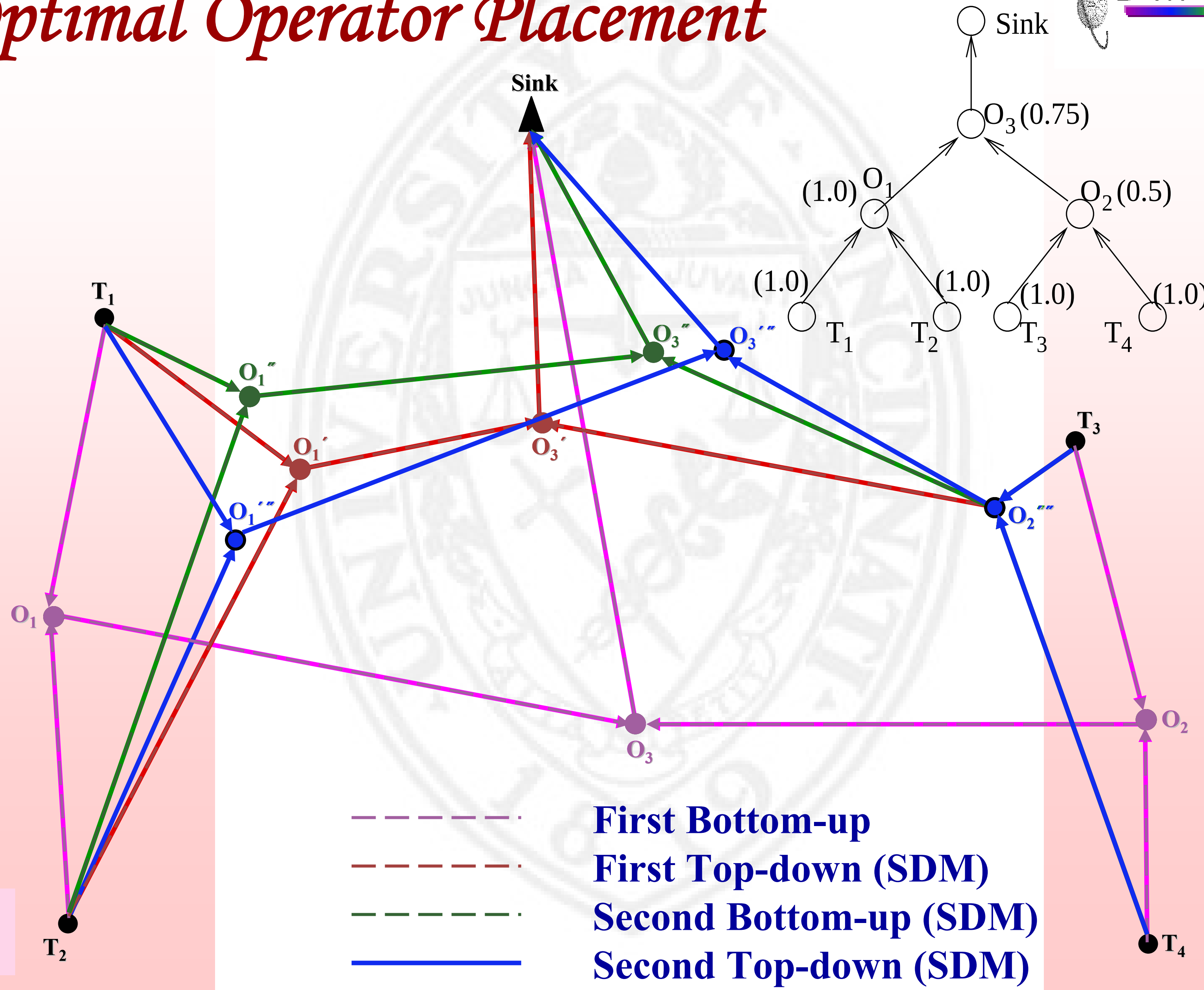
Optimal Operator Placement

- Single operator placement
  - Cost of data transfer for operator placement at X = f(X)
  - $f(X)=||LX||\, d_l + ||RX||\, d_r + ||XP||\, d_p$

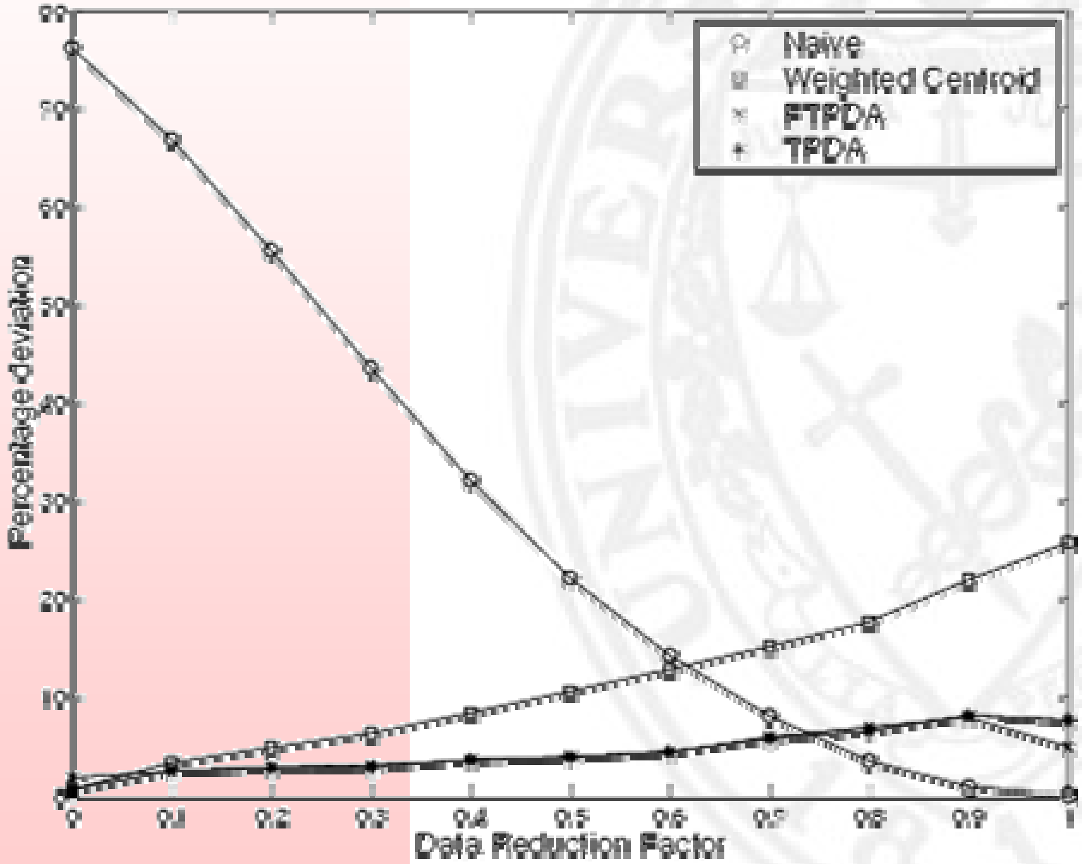


- Optimal placement (X) ⇔ Minima of f(X)
- Use a simple Non-linear Optimization method, 'Steepest Descent' method to find X such that $f'(X) = 0$
  - Issues addressed:
    - Translating query tree to energy aware routing tree
    - Adapting operator placement in a decentralized manner
    - Providing robustness and scalability in a decentralized manner

Optimal Operator Placement



Deviation from Optimal Placement



- Naïve: Data sent from target region to sink for query evaluation
- Weighted Centroid: Operator placed at weighted centroid of child and parent operators
- Two Phase Decentralized Adaptation (TPDA)
- Fast TPDA : Two iterations of TPDA

Experimental test-bed for CO Monitoring

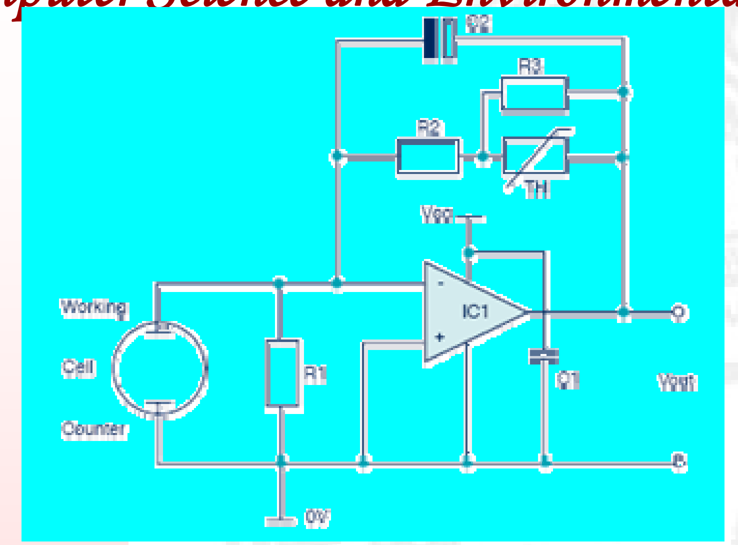
- Monitor the CO in the garage
  - Library garage: ~60m*100m

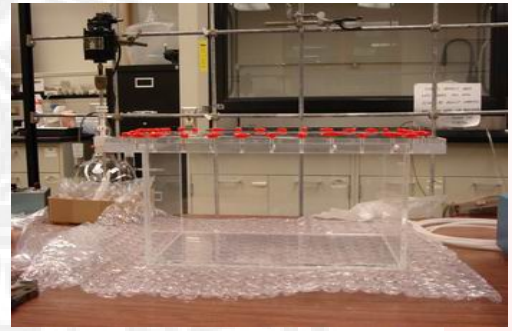
CO Monitoring


- Monitor the CO of the street near UC campus
- National Ambient Air Quality Standards (NAAQS) for CO
  - 1-hour Average: 35 ppm(40 mg/m^3)
  - 8-hour Average: 9 ppm(10 mg/m^3)
- Periodical Sensing
  - Every 15 minutes
  - Reactive (TEEN, APTEEN algorithms)

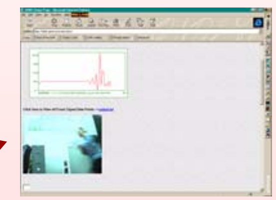
CO Monitoring in UC Campus (Collaborative work between Computer Science and Environmental Engineering)

CO Sensor



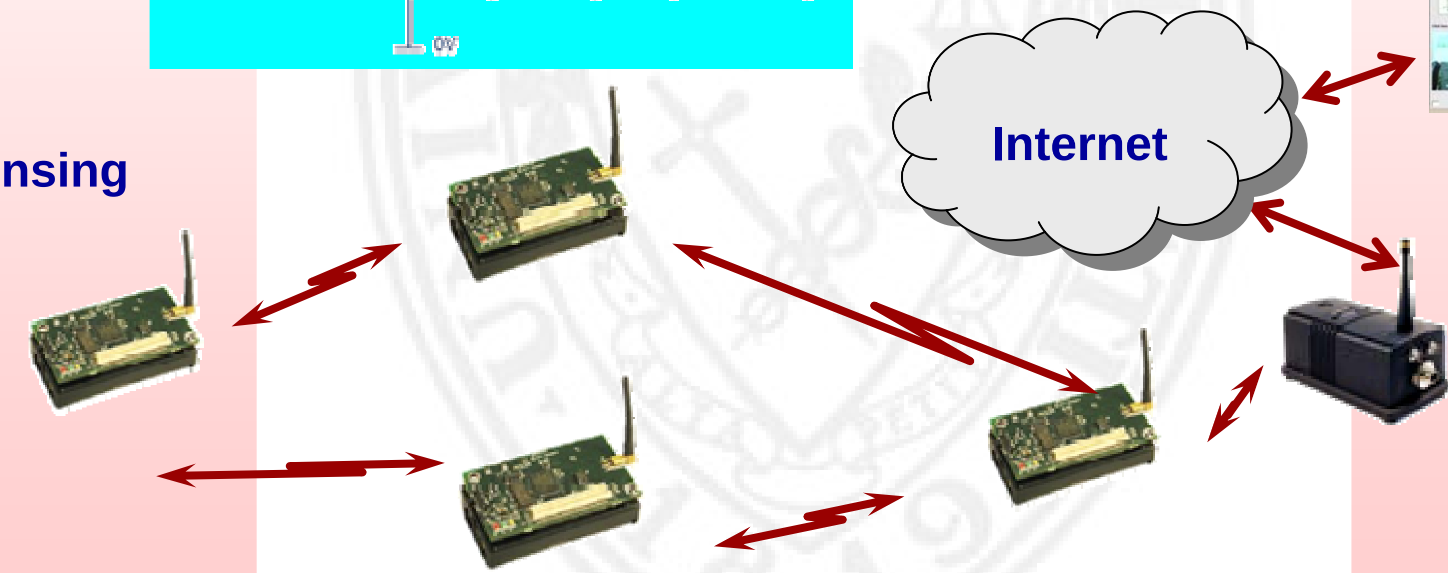


Sensor Calibration Facility



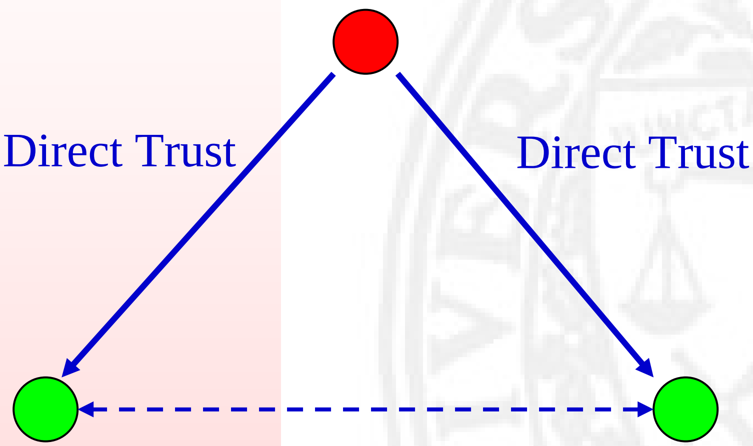
Worldwide User

Sensing



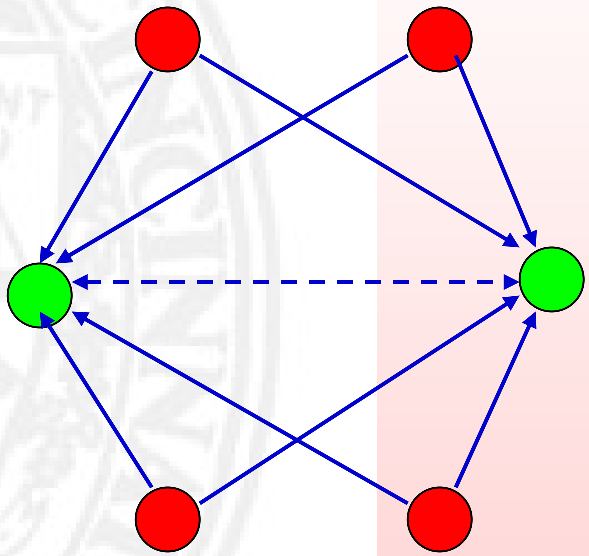
Combination of Sensing, Wireless Technology and Signal Processing for an Event Recognition

Distribution of Trust



Communication using the public key

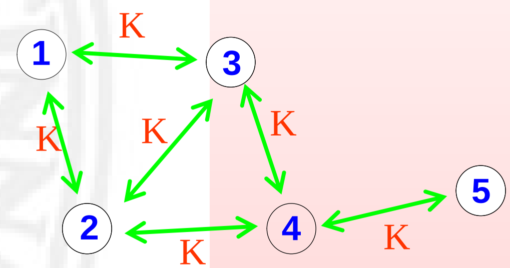
(Indirect Trust)



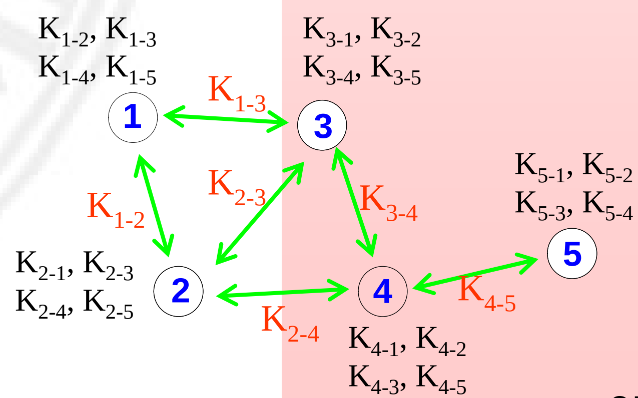
Shares of private keys sent to each node by several Nodes

Key Distribution in Wireless Sensor Networks (WSNs)

- Why not use current security protocols?
  - Public-Key cryptosystems → too complicated
  - Trusted-Server based protocols → no trusted servers exist
- Research shows key pre-distribution is a practicable method for WSNs
  - Pre-assigning a set of secret keys into sensor nodes before deployment
  - Generating pairwise key between sensor nodes after deployment
- Two straightforward solutions
  - Master key approach
    - All sensor nodes share a same master key
  - Pairwise key approach
    - Every pair of nodes has a pairwise key
    - Secure but not efficient



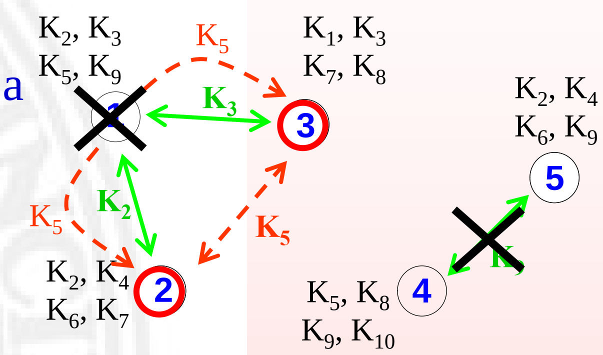
Master Key Approach



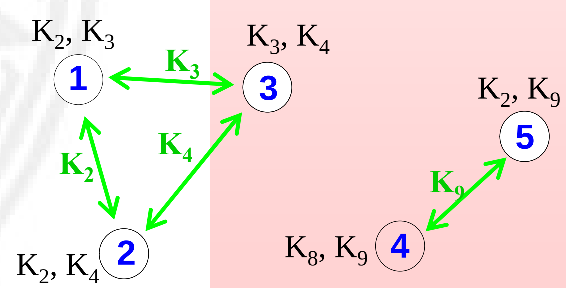
Pairwise Key Approach

Existing Key Pre-distribution Schemes

- Random key pre-distribution scheme (2002)
  - Each node randomly assigned a subset of keys from a large-size key pool
  - Neighboring nodes exchange their key information and setup pairwise key if they have common keys
  - Two communicating nodes need to setup a path-key if they have no shared common keys
- Location-based key distribution scheme (2003)
  - Reduce the number of required keys for sensor nodes
  - Assume nodes' locations are predictable, and nodes can be deployed in their predicted locations with high probability
- Limitations of existing schemes
  - Not support full network connectivity
  - Not energy efficient
  - Deployment info are unpredictable in most applications
  - Not secure for node capture attack



Random Key Pre-distribution



Location-based Key Distribution

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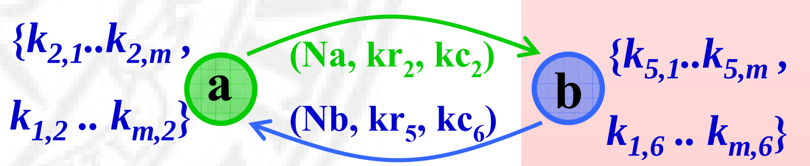
Efficient Pairwise Key Establishment and Management Scheme (EPKEM)

- First, generate a 2-dimensional symmetric key matrix $K_{m \times m}$
- For each node, randomly pre-load a row and a column keys from K into its memory
- Deploy sensor nodes in a sensing field randomly; neighboring nodes exchange their key information
- Any two nodes share at least two common keys
- Neighboring nodes generate pairwise key by exclusive-or their shared common keys and their randomly generated numbers
- After pairwise key generation phase, each node erases its pre-loaded keys to prevent the possible compromise in the future

id	kc_1	kc_2	kc_3	kc_4	kc_5	kc_6	..	kc_m
kr_1	$k_{1,1}$	$k_{1,2}$	$k_{1,3}$	$k_{1,4}$	$k_{1,5}$	$k_{1,6}$	..	$k_{1,m}$
kr_2	$k_{2,1}$	$k_{2,2}$	$k_{2,3}$	$k_{2,4}$	$k_{2,5}$	$k_{2,6}$	..	$k_{2,m}$
kr_3	$k_{3,1}$	$k_{3,2}$	$k_{3,3}$	$k_{3,4}$	$k_{3,5}$	$k_{3,6}$	..	$k_{3,m}$
kr_4	$k_{4,1}$	$k_{4,2}$	$k_{4,3}$	$k_{4,4}$	$k_{4,5}$	$k_{4,6}$	..	$k_{4,m}$
kr_5	$k_{5,1}$	$k_{5,2}$	$k_{5,3}$	$k_{5,4}$	$k_{5,5}$	$k_{5,6}$	..	$k_{5,m}$
kr_6	$k_{6,1}$	$k_{6,2}$	$k_{6,3}$	$k_{6,4}$	$k_{6,5}$	$k_{6,6}$	..	$k_{6,m}$
:	:	:	:	:	:	:	..	:
kr_m	$k_{m,1}$	$k_{m,2}$	$k_{m,3}$	$k_{m,4}$	$k_{m,5}$	$k_{m,6}$	..	$k_{m,m}$

Common Keys



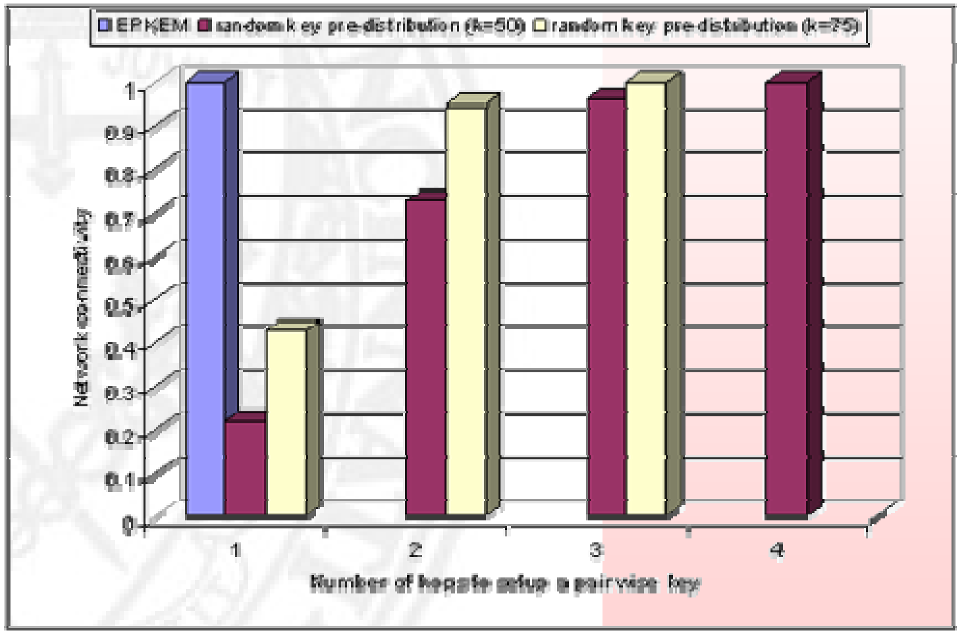
$$PK_{a\text{-}b} = k_{2,6} \text{ XOR } N_a \text{ XOR } k_{5,2} \text{ XOR } N_b$$

Approach of EPKEM

Performance Evaluation

DMC

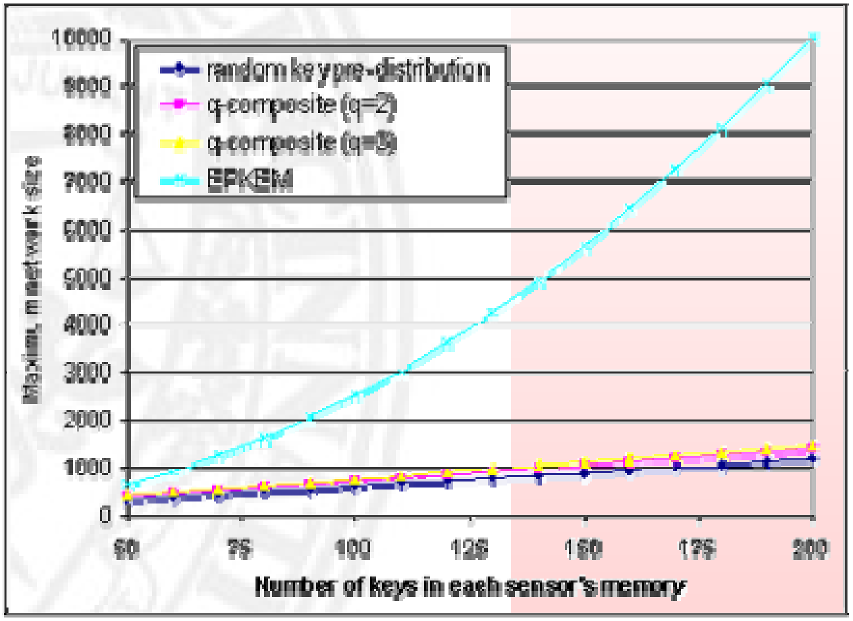
- Connectivity:
  - Sensor nodes can be randomly deployed in the sensing area
  - Any two nodes can setup a pairwise key with their shared common keys
  - Full network connectivity can be guaranteed no matter how and where sensor nodes are deployed
- Efficiency:
  - No intermediate nodes involved in pairwise key generation phase
  - Reduce the communication and computational overheads
  - Improve the security



Network connectivity vs. Number of hops to setup a pairwise key

Performance Evaluation

- Scalability:
  - Better scalability than existing schemes
  - The maximum supported network size is m^2, given $2m$ keys stored in each node
  - The maximum supported network size exponentially increase when the number of keys stored in each sensor node increases linearly
  - Applicable for large-scale WSNs



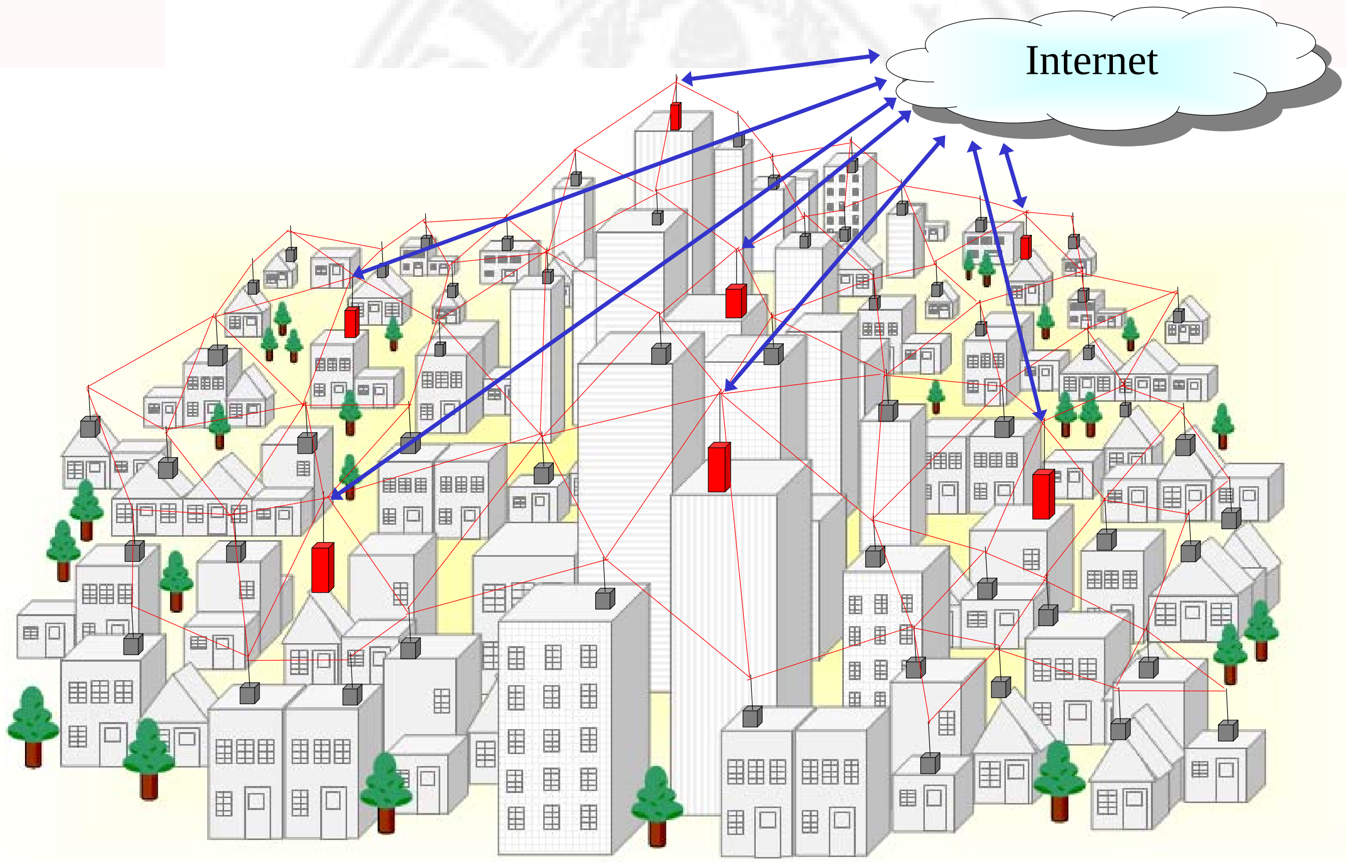
Maximum network size vs.
Number of keys in each sensor node

Wireless Mesh Networks – Challenges and Solutions

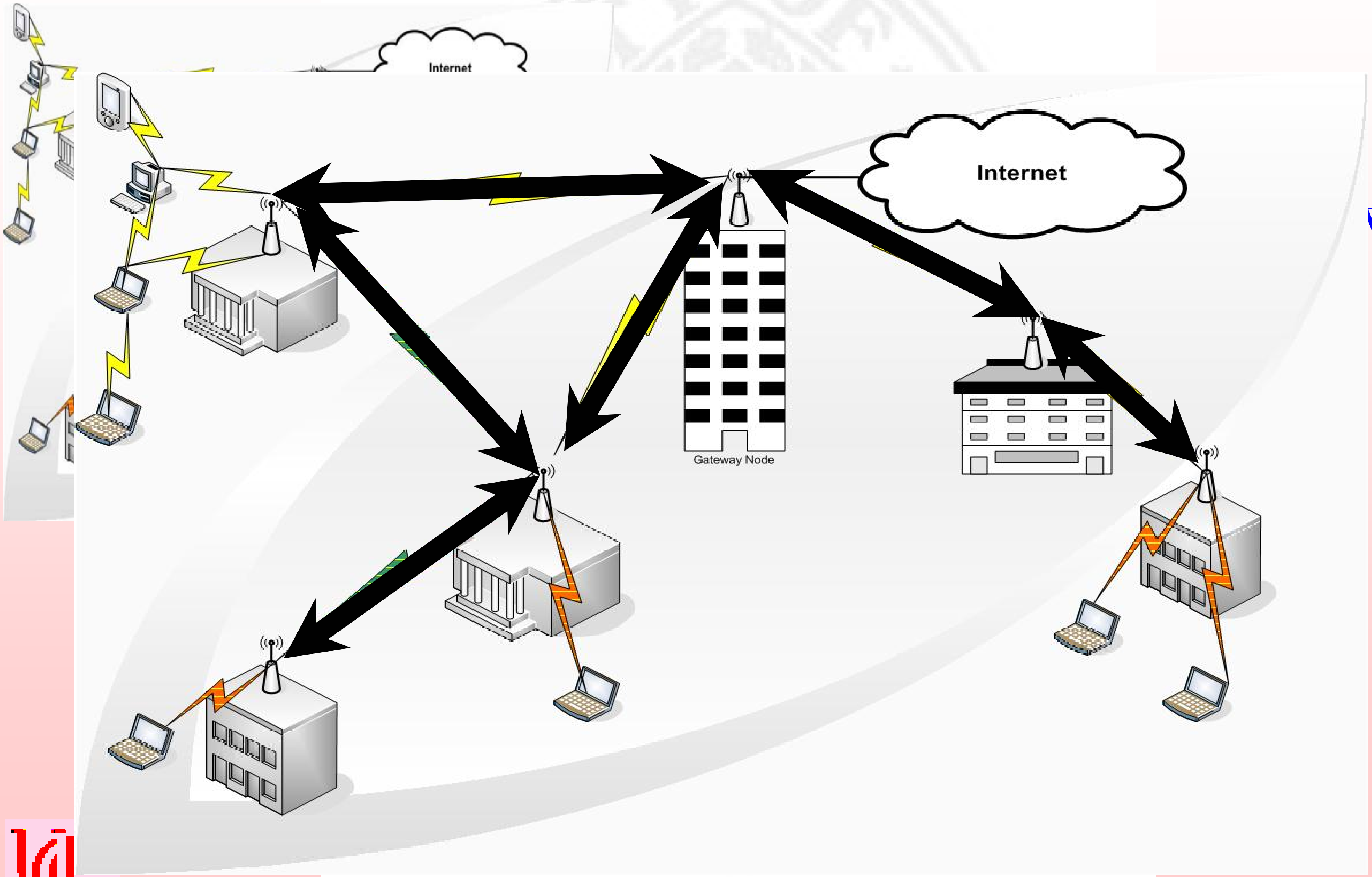
- **Wireless LANs**
  - **Becoming popular in the form of Wi-Fi hotspots**
  - **Public Wi-Fi Hotspots providing ubiquitous Internet connectivity**
  - **Easy and Reliable**

- **Limitations**
  - **Limited coverage**
  - **Wired connection to the APs**
  - **All data carried over wired backhaul**

Wireless Mesh Networks (WMNs)



Wireless Mesh Networks



ve

Unique features of WMNs

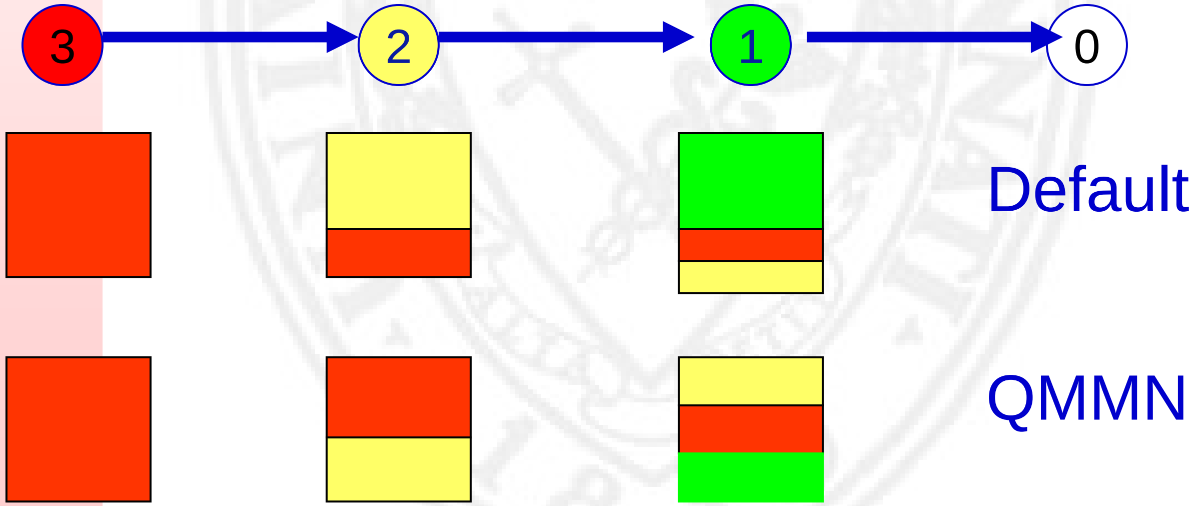
- Mesh Routers are relatively static
  - Can be hooked on poles or corners
- Mesh Routers are not power constrained
  - Continuous power can be easily drawn.
- Mesh Routers are equipped with Multiple Radios
  - Can also be expanded
- Traffic Model is different
  - Its either from Internet or towards Internet!!

Associated Issues

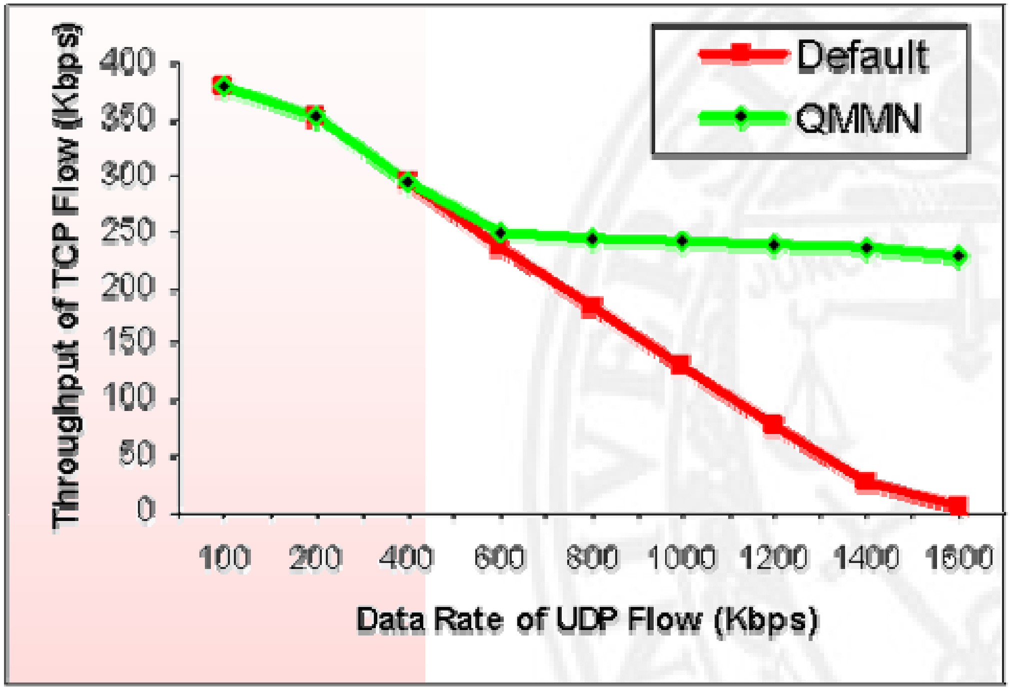
- Coverage and Capacity –
  - Improper planning may render the network useless
- Traffic Engineering –
  - Load Balanced Routing
  - Efficient and uniform use of resources
- Fairness in forwarding traffic
  - Buffer Management [QMMN]
- Cooperation and Selfishness

Queue Management in Mesh Networks (QMMN)

- At each intermediate mesh point:
  - Provide fair share of buffer to all individual sources whose traffic is being forwarded



Results – Backlogged UDP flows



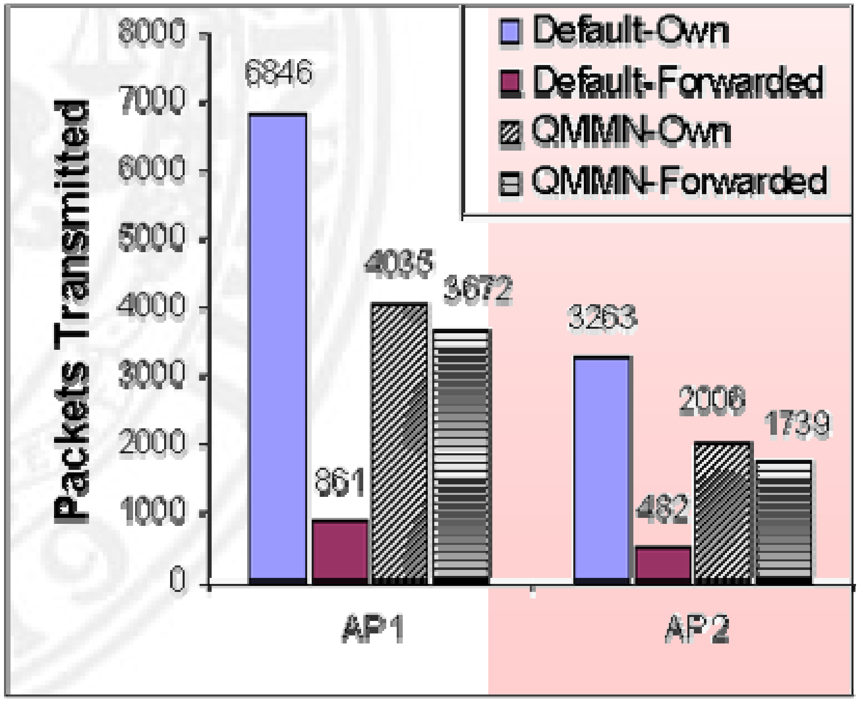
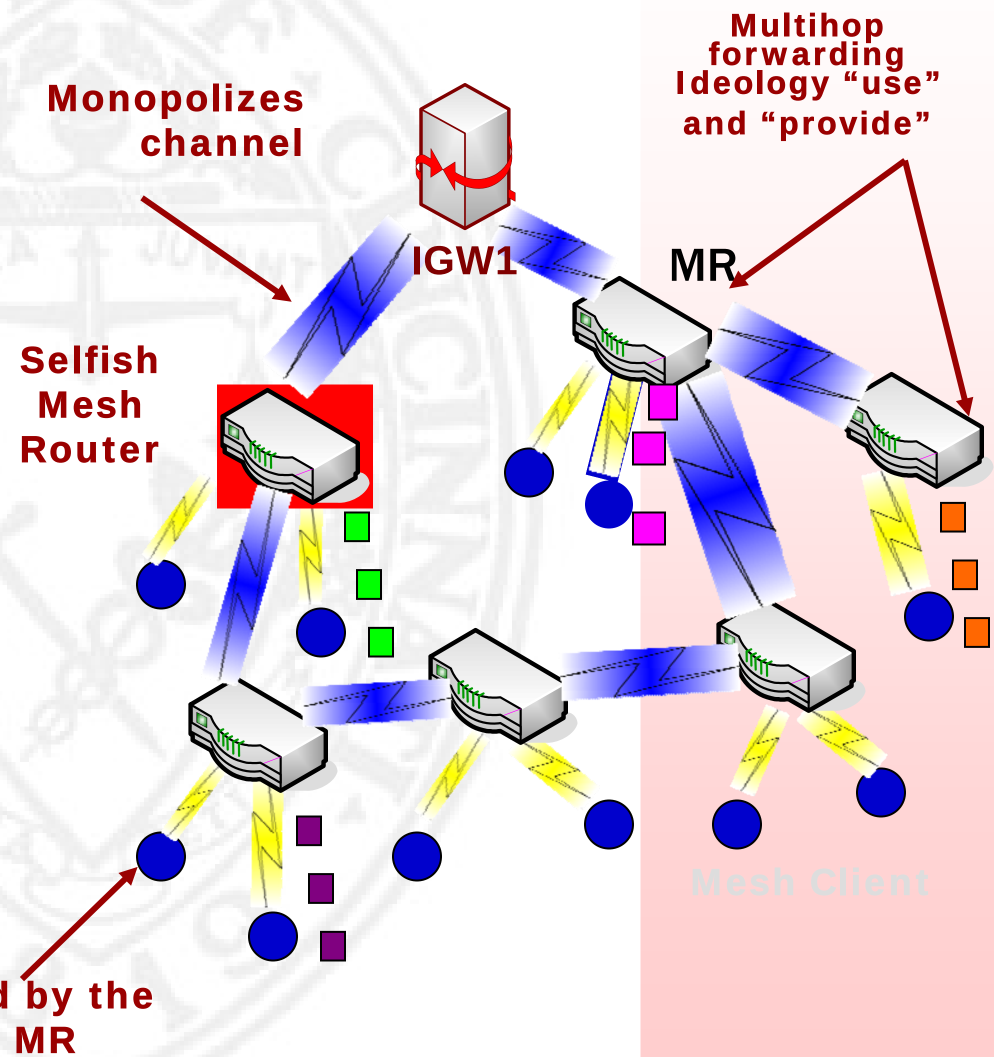


Illustration of a Selfish Node

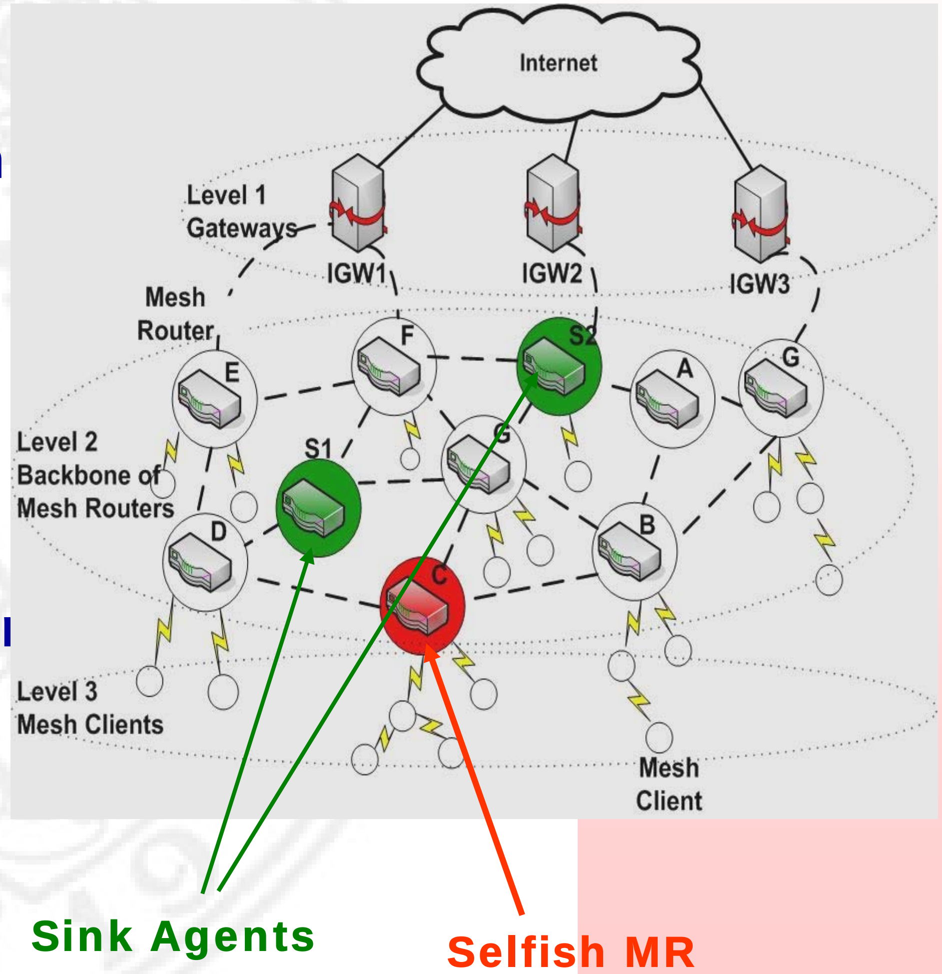
- **Selfish MR**
  Favors its own traffic by dropping other's traffic (partially or fully)
- **Motivation**
  - **Increased throughput**
  - **Avoid Congestion**
- **Policy of Selfish MR**
  - **Residual bandwidth < threshold, MR drops other's packets**
  - **Selfish MS in ad hoc network – always drops to save energy**



Distributed policing Architecture (D-POLICE)

D-SAFNC

- Start-up phase
  - Sink- regulated floodin
  - Registration with sink
- Monitoring phase
  - Submit traffic reports periodically
  - Validate traffic reports with checkpoints
  - Run free rider detectio algorithm (AIMD)



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Selfish MR Detection Algorithm

Threshold: 3

Inconsistency Record Table

- **A-B**
- **C-D**
- **A-D**
- **A-D**
- **C-D**
- **B-D**

"D is a cheater!!!"

	A	B	C	D	Total
A	-	**1**	0	0	**1**
B	**1**	-	0	0	**1**
C	0	0	-	0	0
D	0	0	0	-	0

	A	B	C	D	Total
A	-	1	0	0	1
B	1	-	0	0	1
C	0	0	-	**1**	**1**
D	0	0	**1**	-	**1**

	A	B	C	D	Total
A	-	1	0	**1**	**2**
B	**0**	-	0	0	**0**
C	0	0	-	**0**	**0**
D	**1**	0	1	-	**2**

	A	B	C	D	Total
A	-	1	0	**2**	**3**
B	0	-	0	0	0
C	0	0	-	0	0
D	**2**	0	1	-	**3**

	A	B	C	D	Total
A	-	1	0	**1**	**2**
B	0	-	0	0	0
C	0	0	-	**1**	**1**
D	2	0	**2**	-	**4**

	A	B	C	D	Total
A	-	**0**	0	**0**	**0**
B	0	-	0	**1**	**1**
C	0	0	-	**0**	**0**
D	2	**1**	2	-	**5**

A sink manager obtains a list of inconsistencies from various sink agents and determines the selfish MR by AIMD

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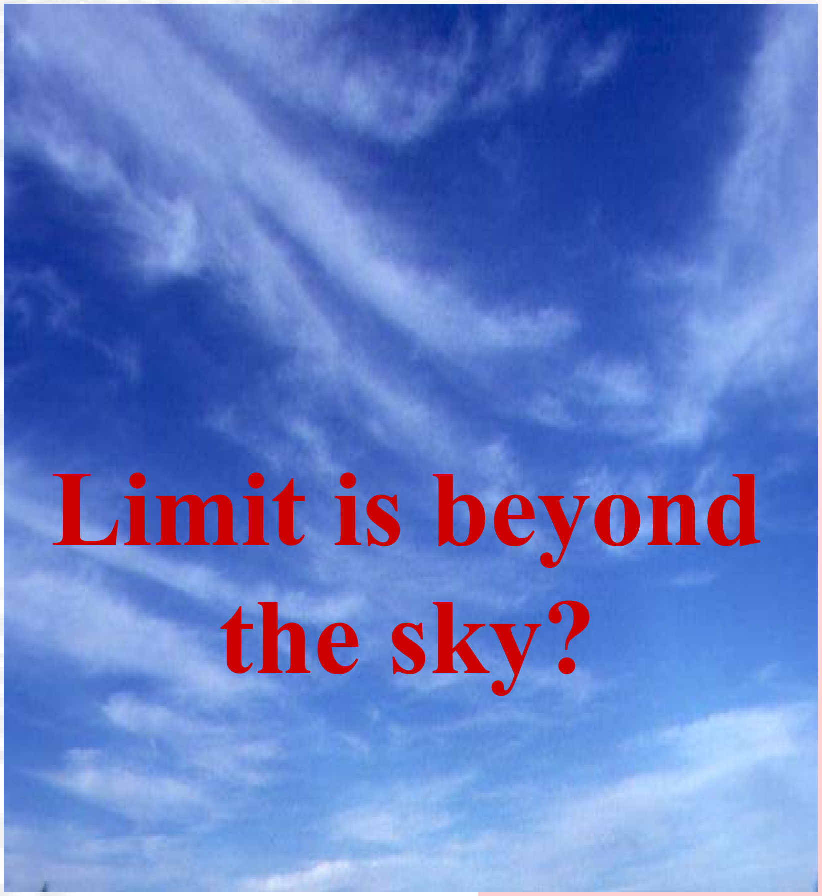
Summing up Wireless & Mobile Technology……



What About Future?

Honey, aren't you feeling hot at home?

I have installed secured sensor unit in each room and is displayed at the central panel !!

A Gaucho (cowboy) in Brazil

DMC

Questions???

University of Cincinnati

Department of Computer Science

Center for Distributed and Mobile Computing