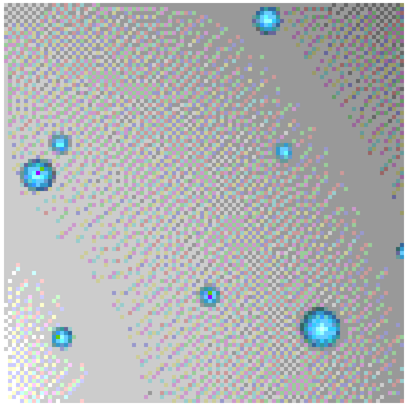
Lecture 0:
Introduction with a bias towards applications



Anish Arora

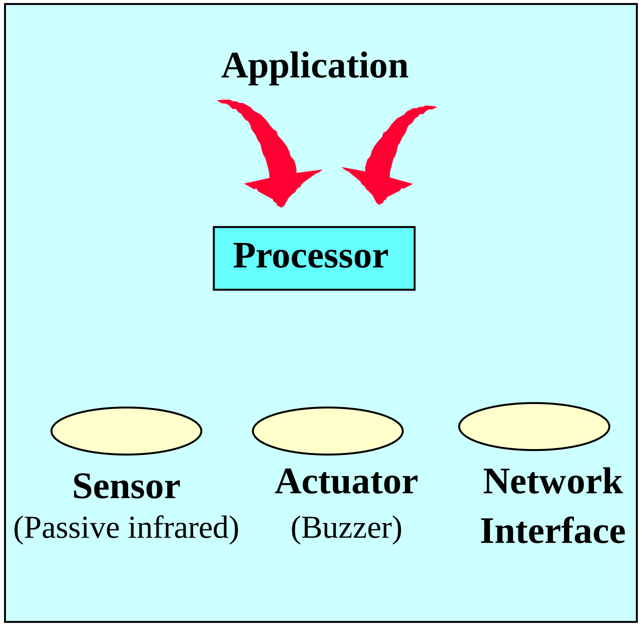
CSE5469

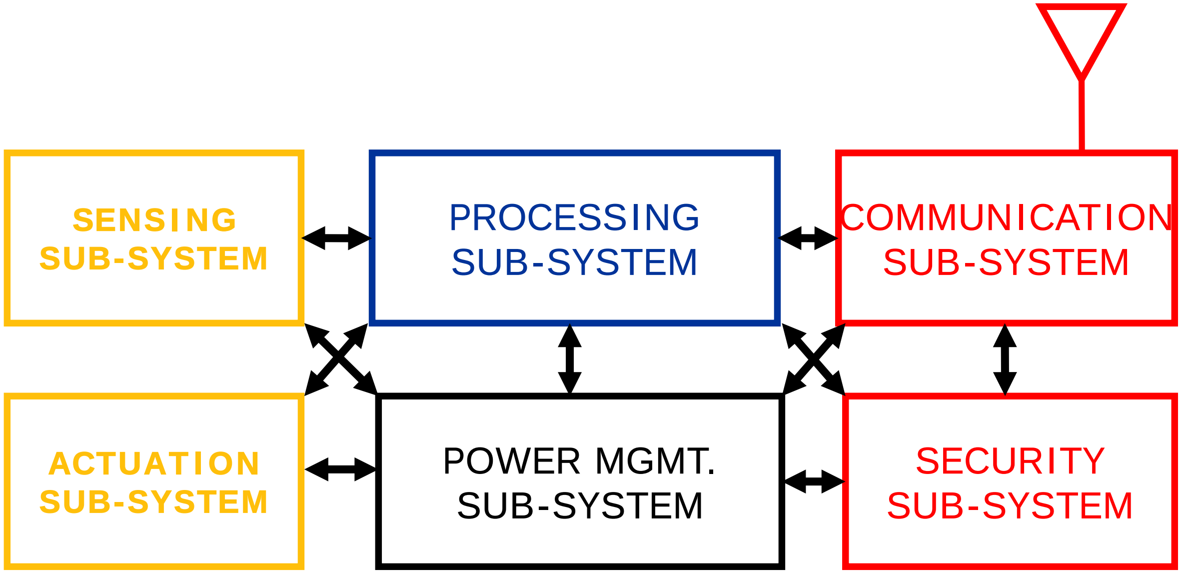
WSN, IoT, MANETs

Outline

- Anatomy of a wireless sensor network (WSN)
- Brief overview of some application contexts: Project *ExScal* and *Tiger Protection*
- More on application contexts
- Anatomy of a MANET
- State-of-the art MANETs

Anatomy of a sensor(-actuator) node



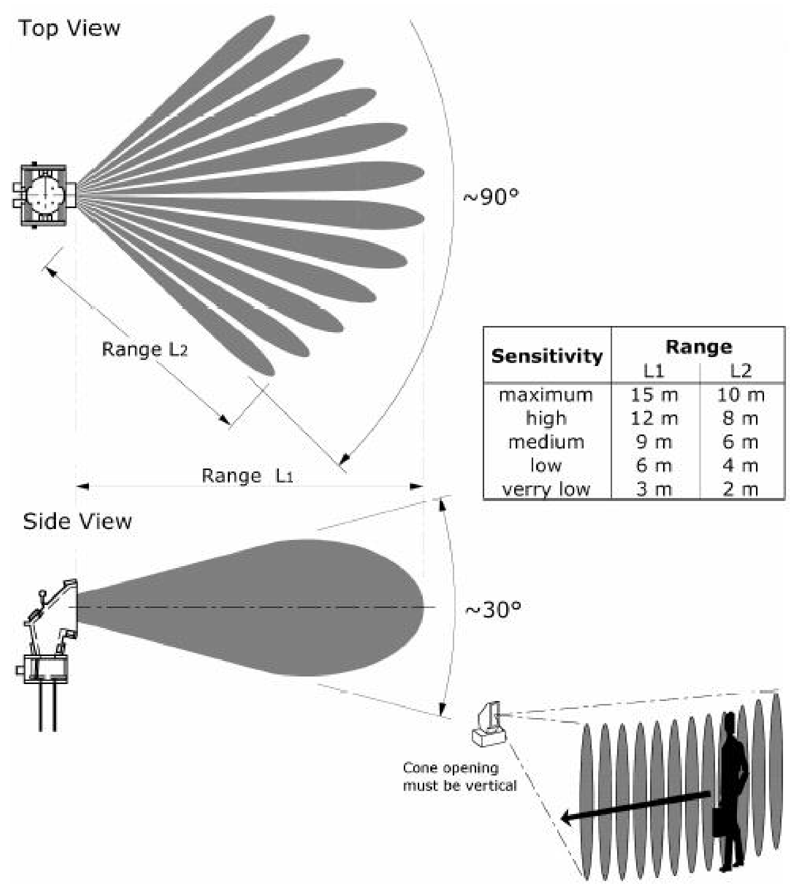


Attitude: Freely choose physical variable of interest !

Another: Killer apps will multiply when actuation closes the loop

An example of a sensor: Passive infrared

PIR is a differential sensor: detects target as it crosses the "beams" produced by the optic

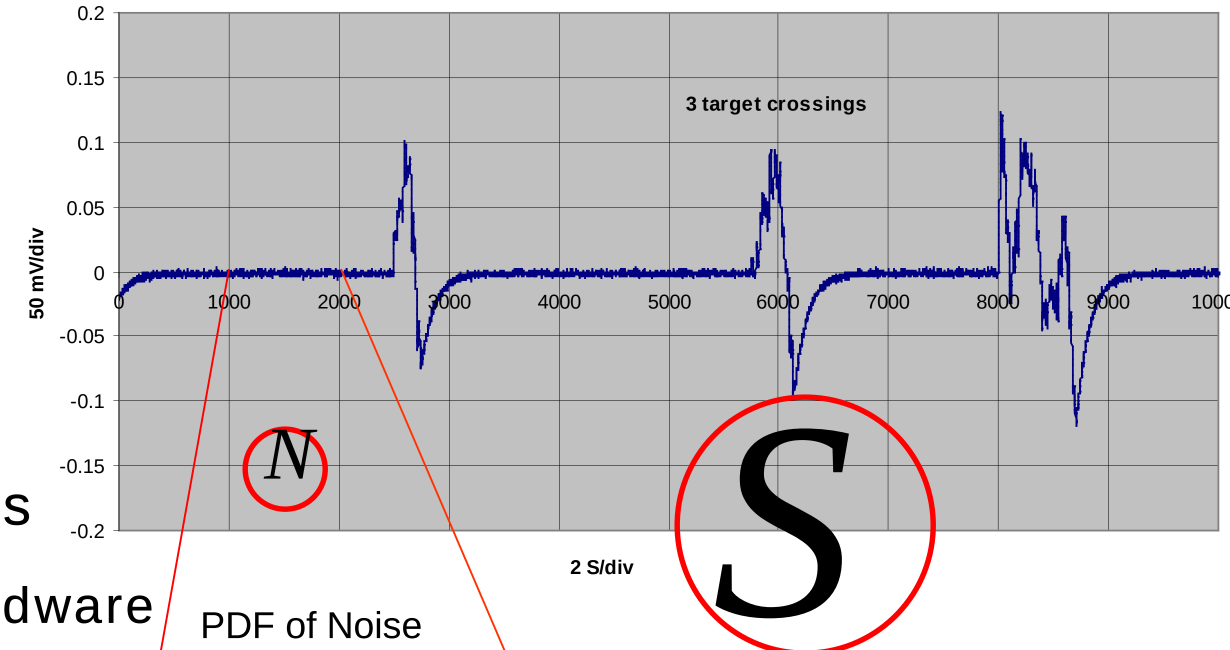


Sensitivity	Range L1	Range L2
maximum	15 m	10 m
high	12 m	8 m
medium	9 m	6 m
low	6 m	4 m
verry low	3 m	2 m

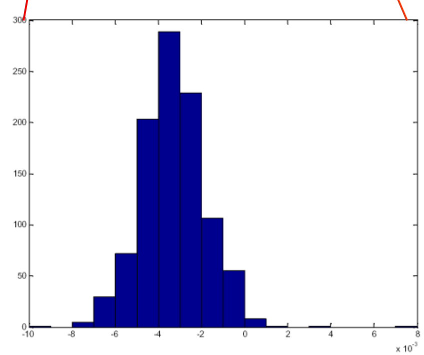
A PIR sensing application

Detect & classify

presence of target



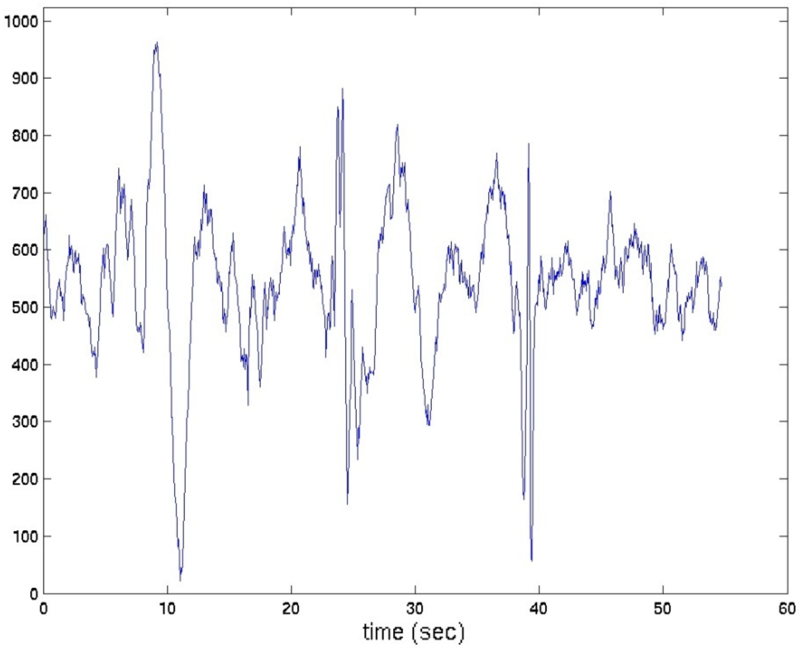
PDF of Noise
Kurtosis = 2.97



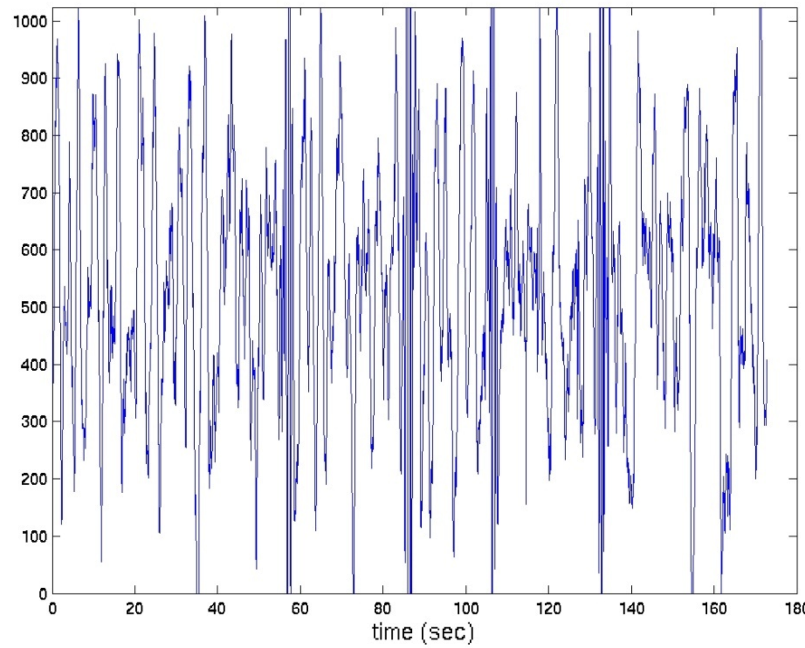
Application components

- signal conditioning hardware
- analog to digital converter
- driver
- sampler
- target detector & classifier

PIR signal: Amplitude

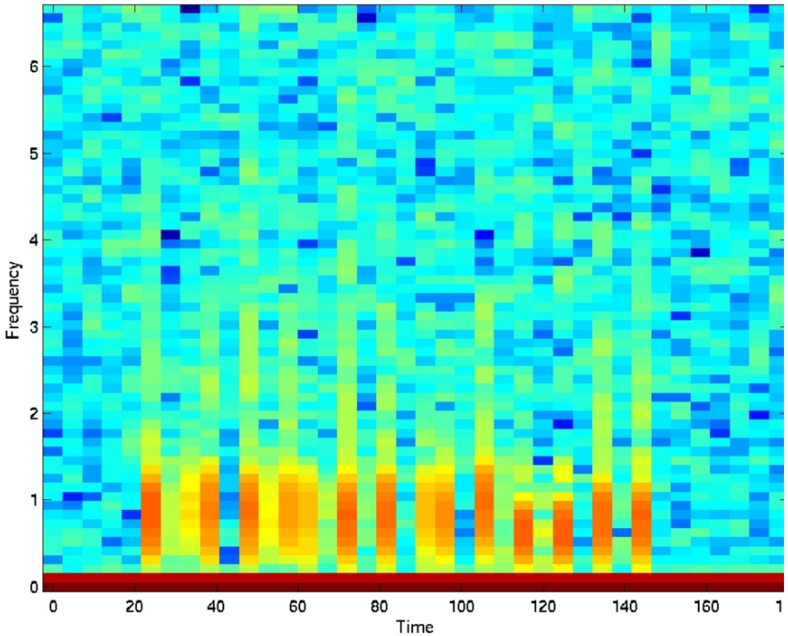


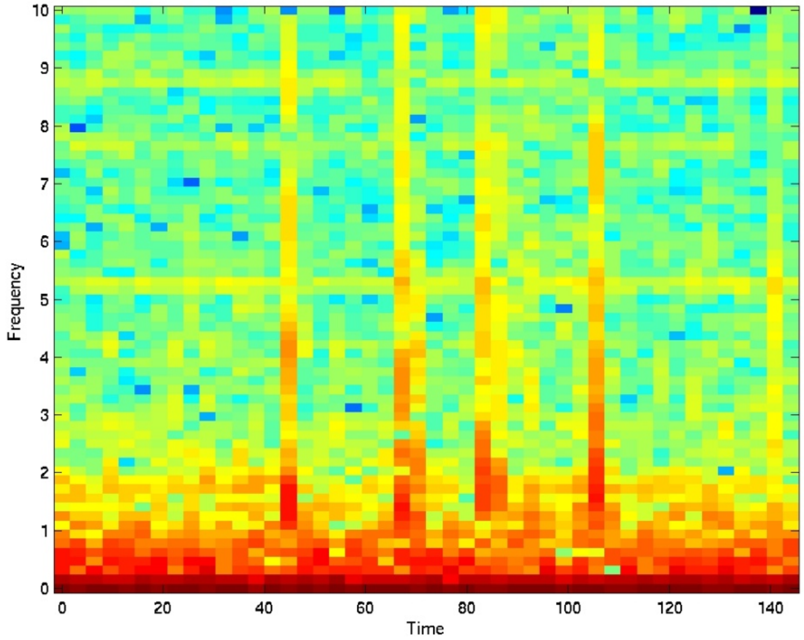
Human
3 mph @ 10m



Car
20-25 mph @ 25m

PIR signal: Frequency



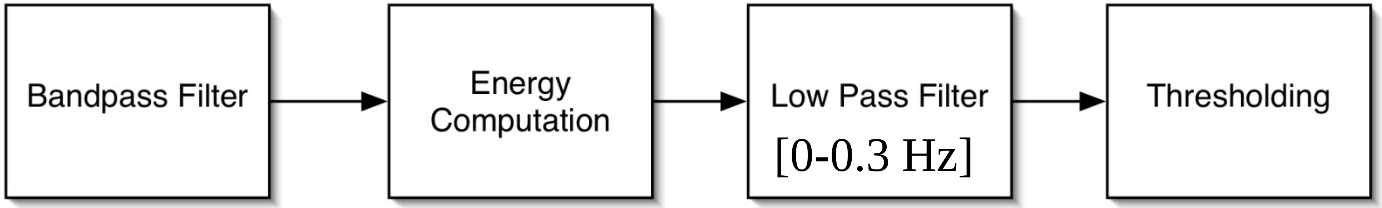


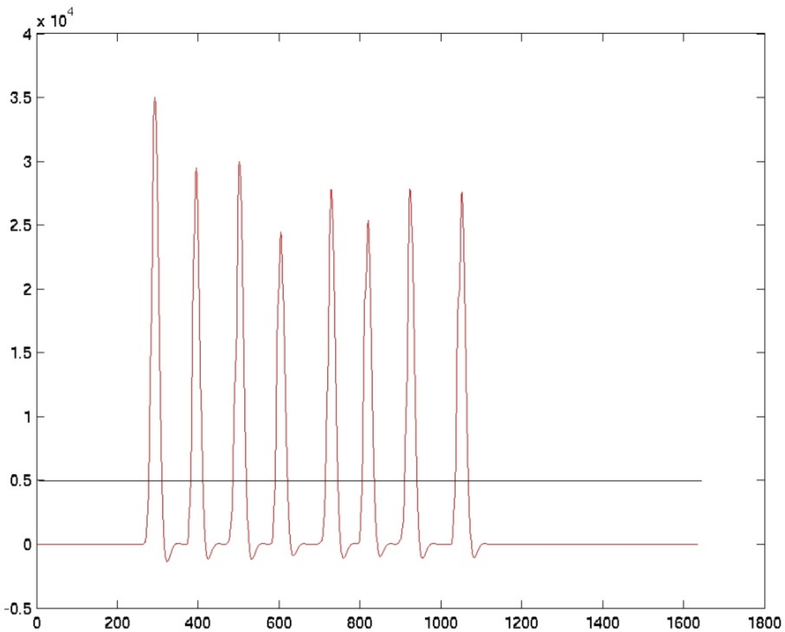
Human at 10 m

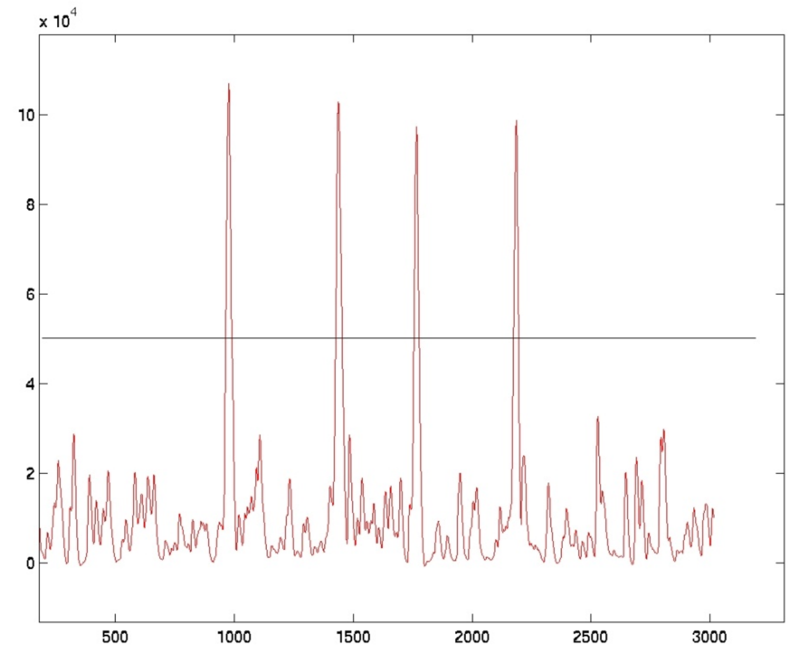
Car at 25m

Energy content for these two targets is in low frequency band

Pir target detector







Person at 12 m

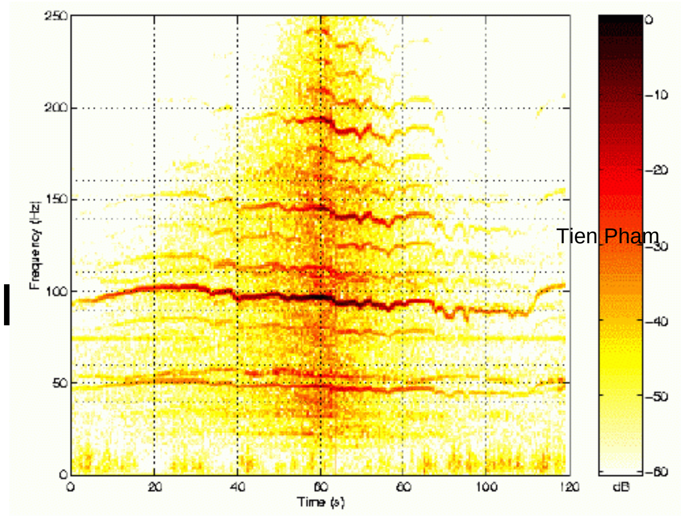
Bandpass: [0.4- 2 Hz]

SUV at 25 m

Bandpass: [2- 4 Hz]

Sensor nodes may be resource rich or poor

Sample *feature* concept: characterize targets by a unique, sophisticated *time-frequency signature*



Resource-rich sensor nodes centrally execute resource intensive algorithm to match signatures; implies focus on signal processing

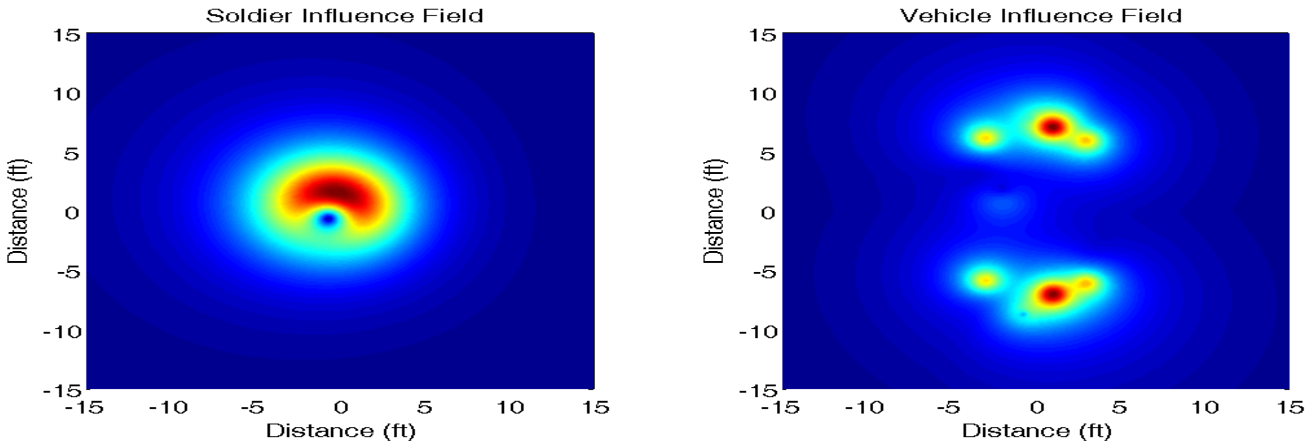
Resource-limited sensor nodes imply focus on networking & distributed computing

A distributed classification approach

Assume a dense WSN

- Concept: each target type has unique *influence field*
- Multiple sensors which detect target coordinate,

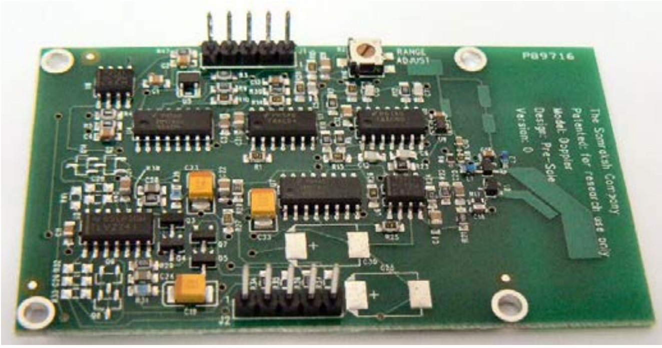
  potentially each with multiple sensing modalities
- Classification is via reliable estimation of influence field size

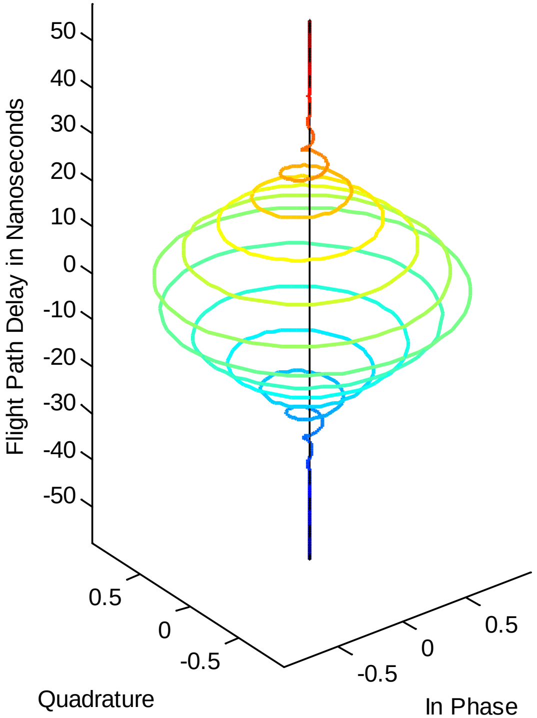


[Computer Networks 2004]

An example of signal processing: Radar basics

- Coherent (i.e., complex output) impulse radar
  - medium bandwidth (~100Mhz)
  - short range (~12m omni), low-power, low-cost
  - not a ranging radar, 1 range bin
- Compute features in amplitude, phase, frequency
  - often physically inspired
- Phase corresponds to range
  - on scale of wavelength
  - accumulating phase changes reveals relative displacement





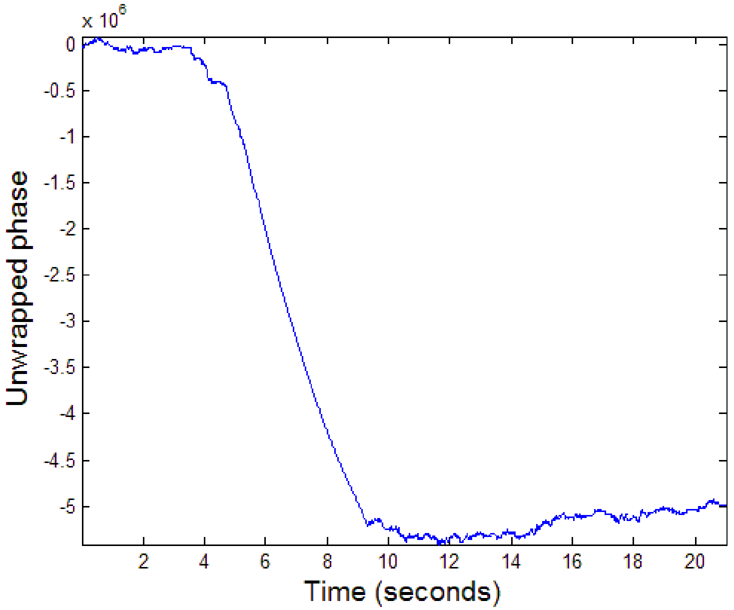
Feature based design: Where possible, design features that are robust

E.g., motion detection features *not* robust

- typically high false alarms for moving bushes and trees

Use *displacement detection* feature instead

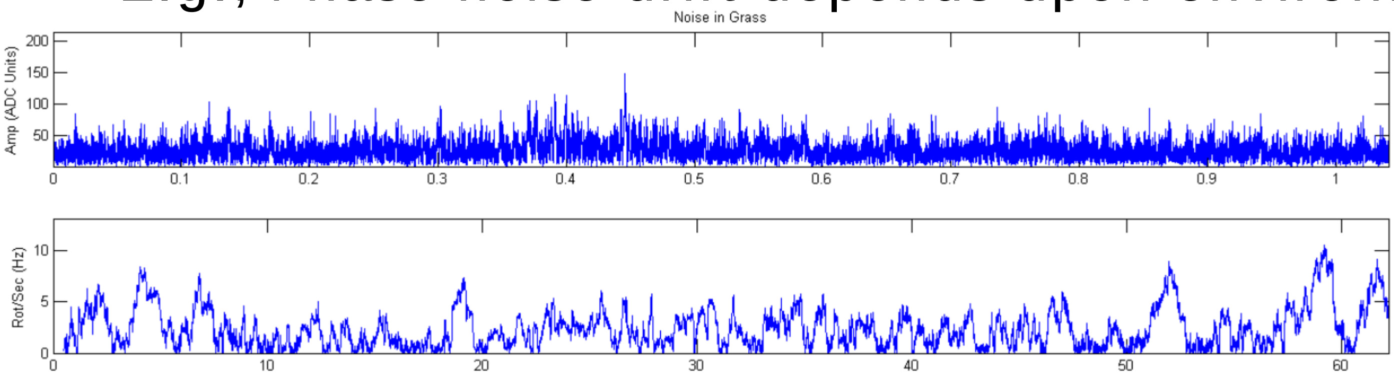
- compute unwrapped phase from consecutive in-phase (I) and quadrature (Q) samples
- unwrapped phase estimates displacement distance
- rejects clutter moving in situ such as bushes and trees



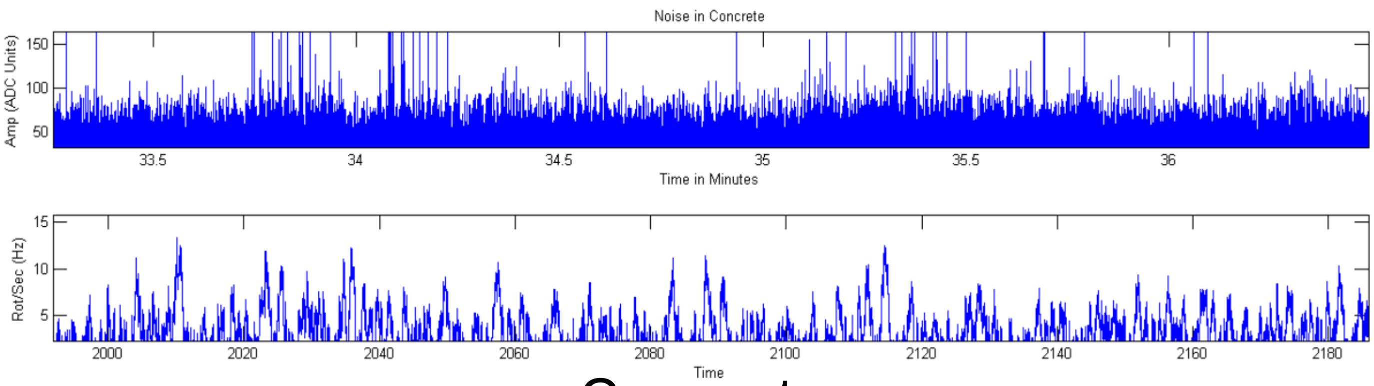
Unwrapped phase over time: a human walks from second 5 to 10

Feature implementation also must tolerate radar sensitivity artifacts

E.g., Phase noise drift depends upon environment



Grass

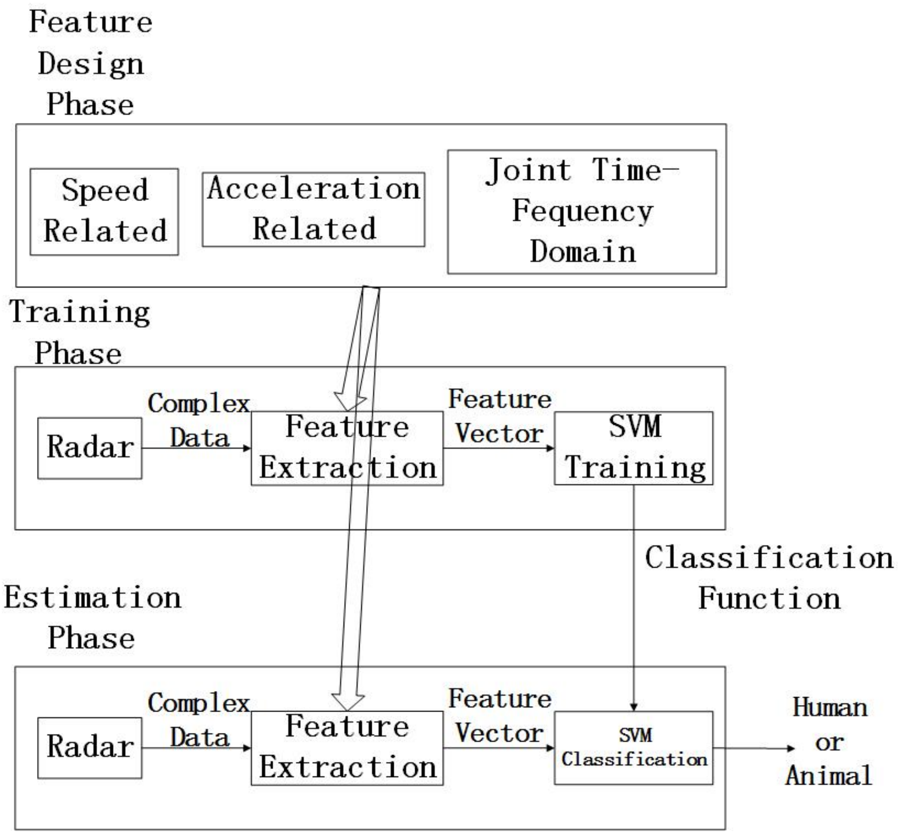


Concrete

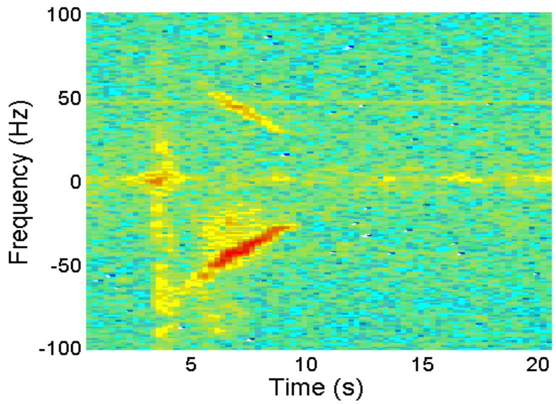
Solution: increase robustness by background noise estimation & online adaptation for noise rejection and threshold selection

Alternative design: engineer data-driven features

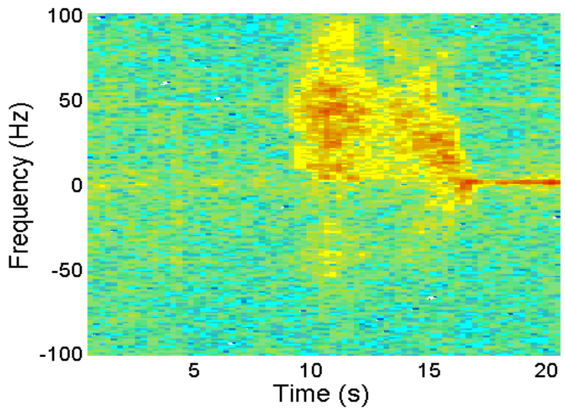
Classification



- E.g., joint time–frequency domain features
  – anomaly area



Dog



Human

Why? As physics based classifier design is hard

Velocity Oriented:

- Moments of velocity could discriminate humans
  - Human movement less smooth
- Velocity profile suggests range at Closest Point of Approach
  - Combine with amplitude for coarse size estimation

Micro-Doppler Statistical:

- Humans likely to have more frequency variability
  - Due to limb motion
  - Look at variability of spectrogram wrt time
- Look at region of spectrogram above background
  - Compute general statistics on this region like spread and moments

Classes of features (contd.)

Gait Specific Micro-Doppler :

- Look specifically for the rhythmic motion of the limbs

Super Resolution :

- Use spectrogram features better than STFFT, e.g. wavelets

Time Warping :

- Human motion is only quasi-periodic
  - Each stride has a slightly different period
- Apply a continuous warping of time to make the motion more periodic
  - Like auto-focusing the motion of the limbs

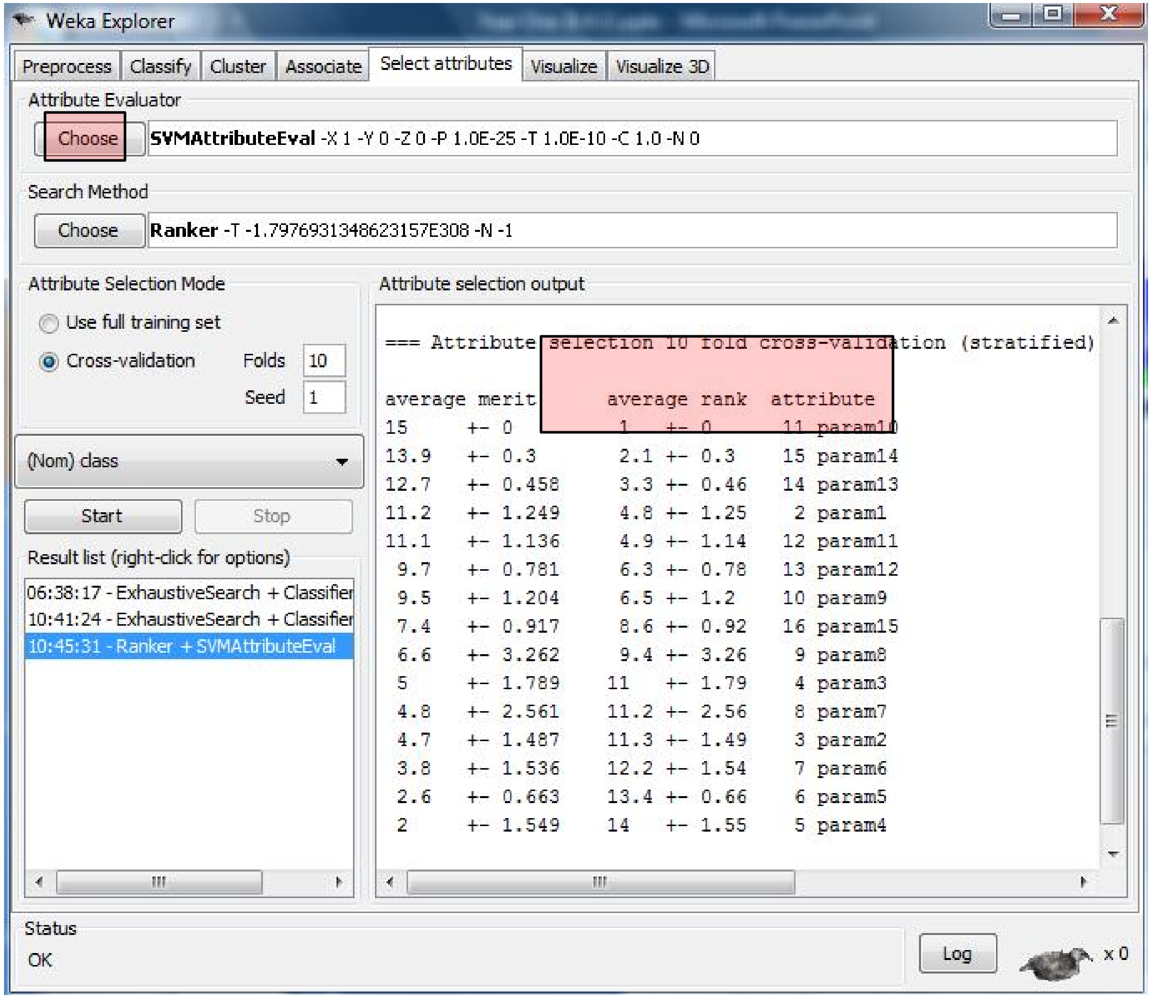
Machine learn the classifier: Training methodology

- Collect data for:
  - background (noise and clutter, different weather conditions)
  - humans
  - target animal (e.g. dog)

- Compute feature values for all logically relevant parameter options

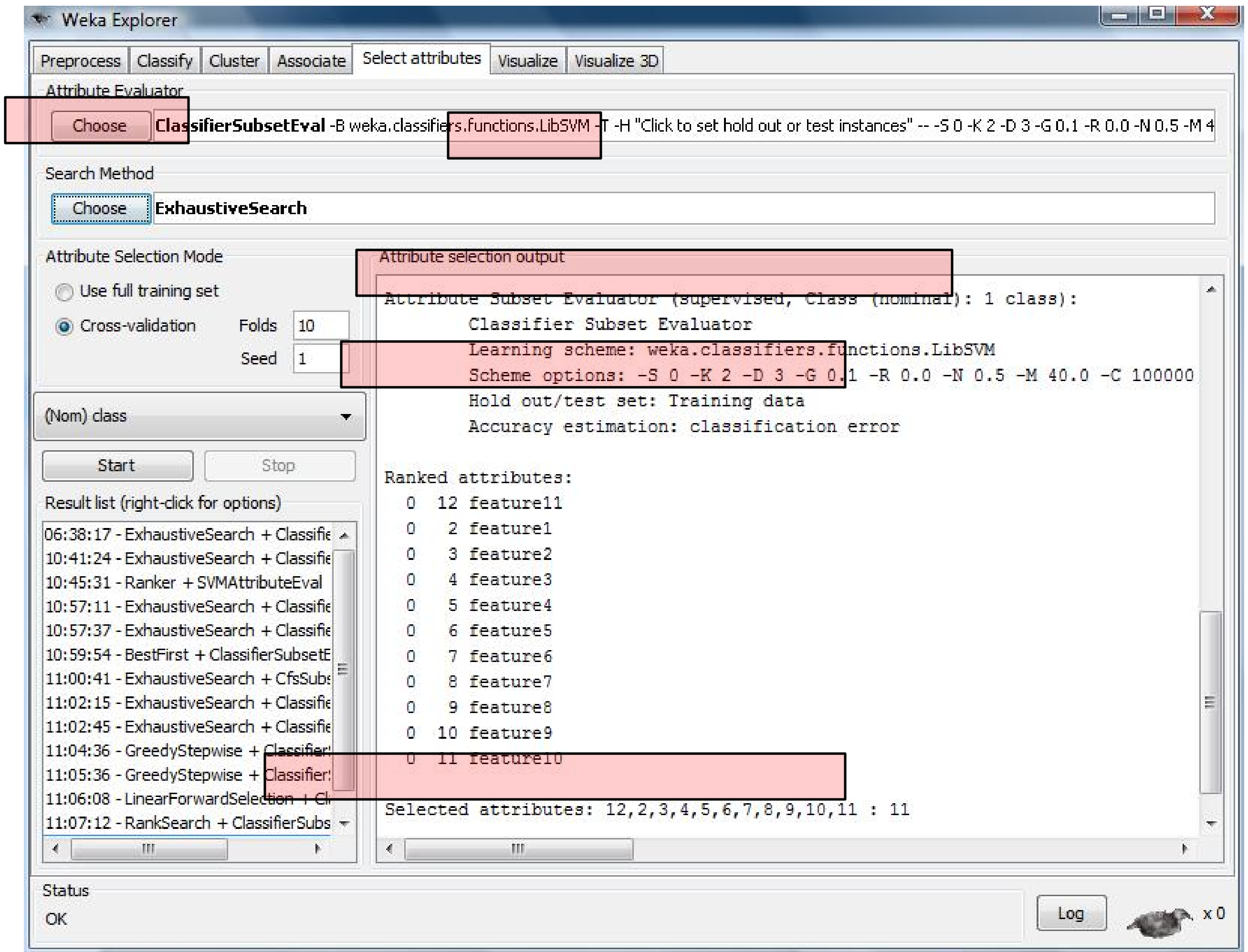
- Perform feature selection
  - e.g., 10 feature classes, each with 125 parameter variations, yields 1250 total features
  - exhaustive selection of parameters and features for the classifier is practically impossible

Feature selection (1)



Rank parameter combinations for each feature class to select top 2 or 3

Feature selection (2)



Exhaustively search for feature subset with best accuracy
Result depends on choice of classification algorithm

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- Anatomy of a wireless sensor network (WSN)
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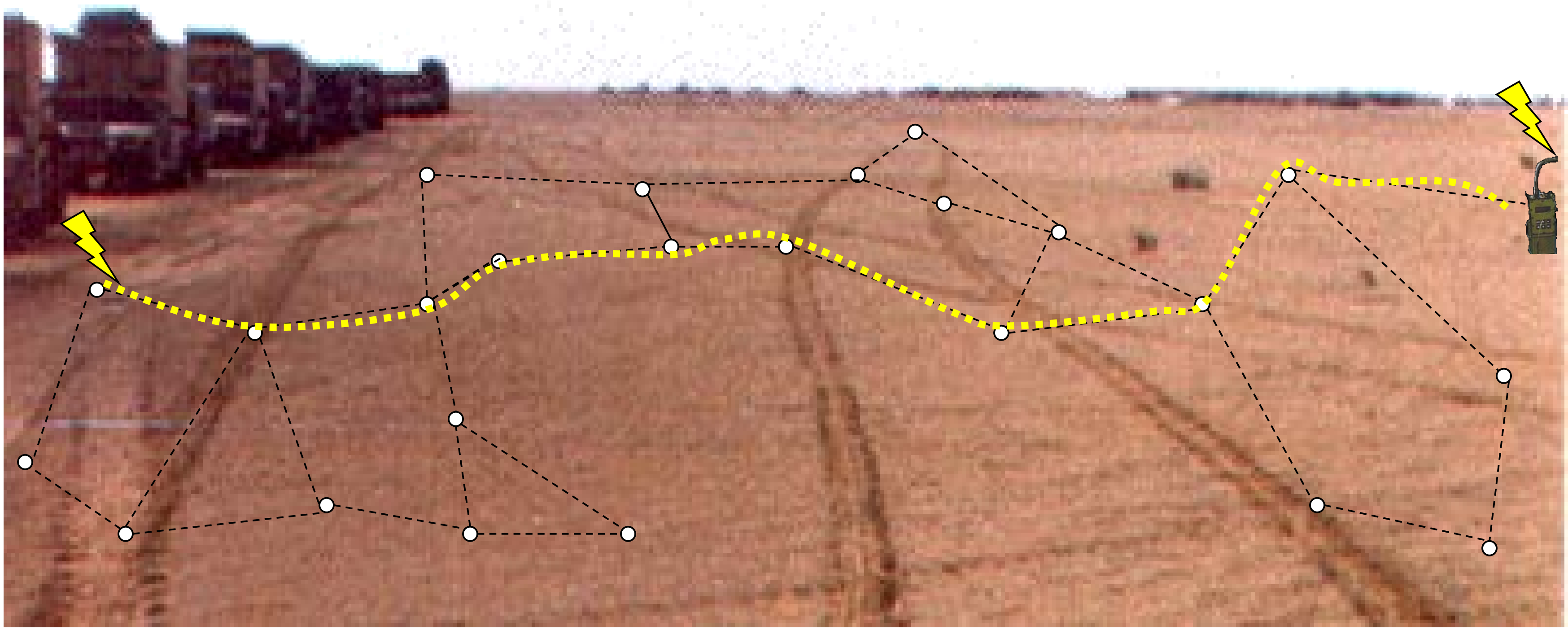
Project *ExScal*: Concept of operation

Put tripwires anywhere—in deserts, other areas where physical terrain does not constrain troop or vehicle movement—to detect, classify & track intruders [Computer Networks 2004, ALineInTheSand webpage, ExScal webpage]



ExScal scenarios

(1) Border Monitoring:

- Detect movement where none should exist
  - Decide target classes, e.g., foot traffic to tanks
- Ideal when combined with towers, tethered balloons, or UAVs

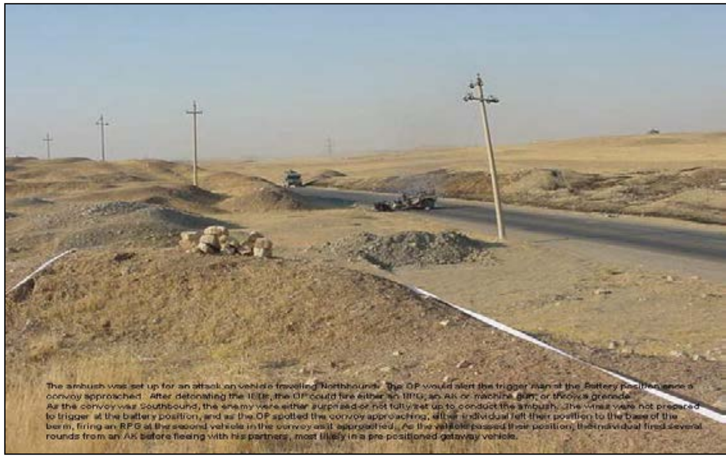
(2) Littoral operations:

- Submersibles & small boats in littoral regions require proximal sensing
  - Communication can be acoustic
  - Good environment for energy harvesting

ExScal scenarios (continued)

(3) Construction Detection:

- Detect anomalous activity
  - E.g., cars go by often, but no one should stop or start digging
- Requires persistent surveillance and in-network pattern matching



(4) Movement in Tunnels:

- The ultimate environment for defeating long range sensing

(5) Urban Operations:

- Tactical Situational Awareness
  - Movement indoors and between buildings
  - Rapid dissemination to combatants

Salient characteristics of ExScal: Coverage

- Lowest cost per area came from remote control camera tower
  - ~$100K per tower & ~8 km range
  - ExScal cost ~$160 per node & ~1000 per sq km, yields about $160K per sq km
  - Price will drop to $10K per sq km, (soon) but not much below that

- In nice terrain camera tower covered most of the area

- Even in ideal terrain *“the other 5%”* is operationally significant

Persistence

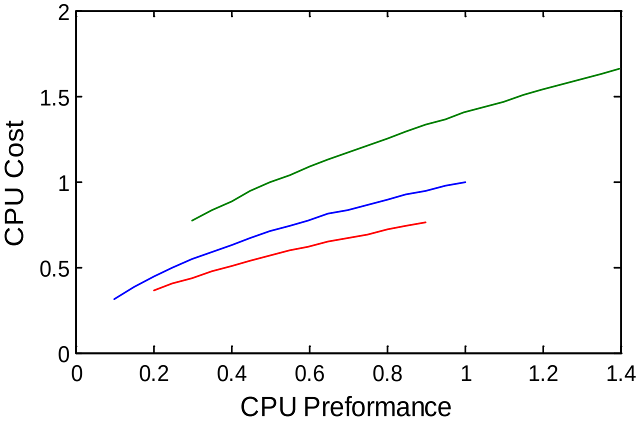
- Many air-to-ground sensors are optimized for short-duration high-urgency use
- Several scenarios however need persistence surveillance
  - Catching infiltrators, early warning, anomaly detection, etc.
- Persistence favors:
  - **Ground based:** no moving parts
  - **Ad-hoc configuration:** self managing, if need be, "*overseed*" repair process
  - **Wireless:** minimal footprint
- Nodes need not be small, but ...
- ExScal like network well suited for persistent surveillance

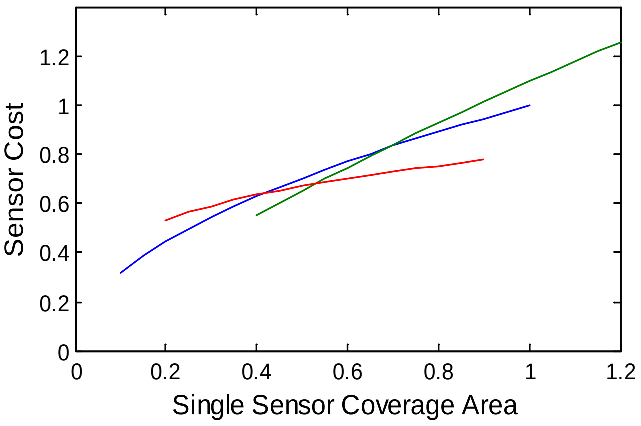
Capital cost

- Sensor cost grows slower than coverage area
  - Conclusion: buy one really expensive sensor

- Like Grosch's (first) Law
  - CPU cost grows as the square root of CPU performance
  - Conclusion: buy the biggest computer you can afford
  - Justified IBM mainframes ('65)

- Conclusions no longer valid, but Grosch's Law still mostly holds
  - Measure of NRE, not price





ExScal sample scenarios

Intruding person walks through thick line

- (pir) detection, classification, and fine-grain localization

Intruding ATV enters perimeter and crosses thick line

- (acoustic) detection, classification, and fine-grain localization

Person/ATV traverses through the lines

- coarse-grain tracking

Management operations to control signal chains, change parameters, and programs dynamically; query status and execute commands

ExScal summary

- Application has tight constraints of event detection scenarios: long life but still low latency, high accuracy over large perimeter vigilance area
- Demonstrated in December 2004 in Florida
- Deployment area: 1,260m x 288m
- ~1000 XSMs, the largest WSN
- ~200 XSSs, the largest 802.11b ad hoc network
- Design, development, integration time: 15 months
- Field setup & experimentation time: 2 weeks
- Team: ~50 people
- Budget: ~$5M, 10,000 nodes manufactured

Key issues at extreme scale

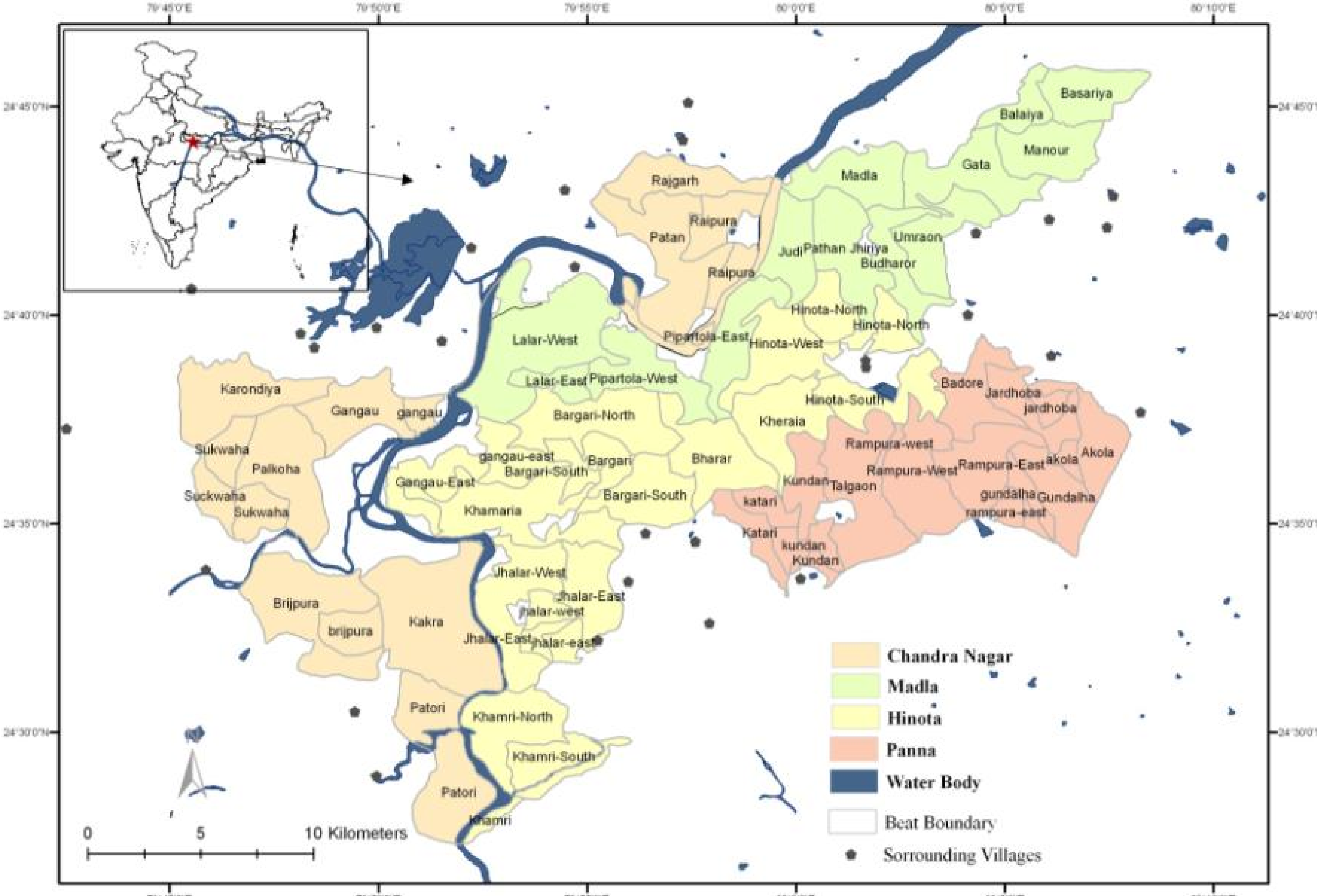
For large area, how to achieve :

1. cost effective coverage ($\Rightarrow$ minimum # of nodes)
   - scale sensing & communication ranges
   - lower power consumption
   - efficient coverage

2. robust, reliable, timely & accurate execution
   - optimize services for scenario requirement
   - tolerance to deployment errors & component faults

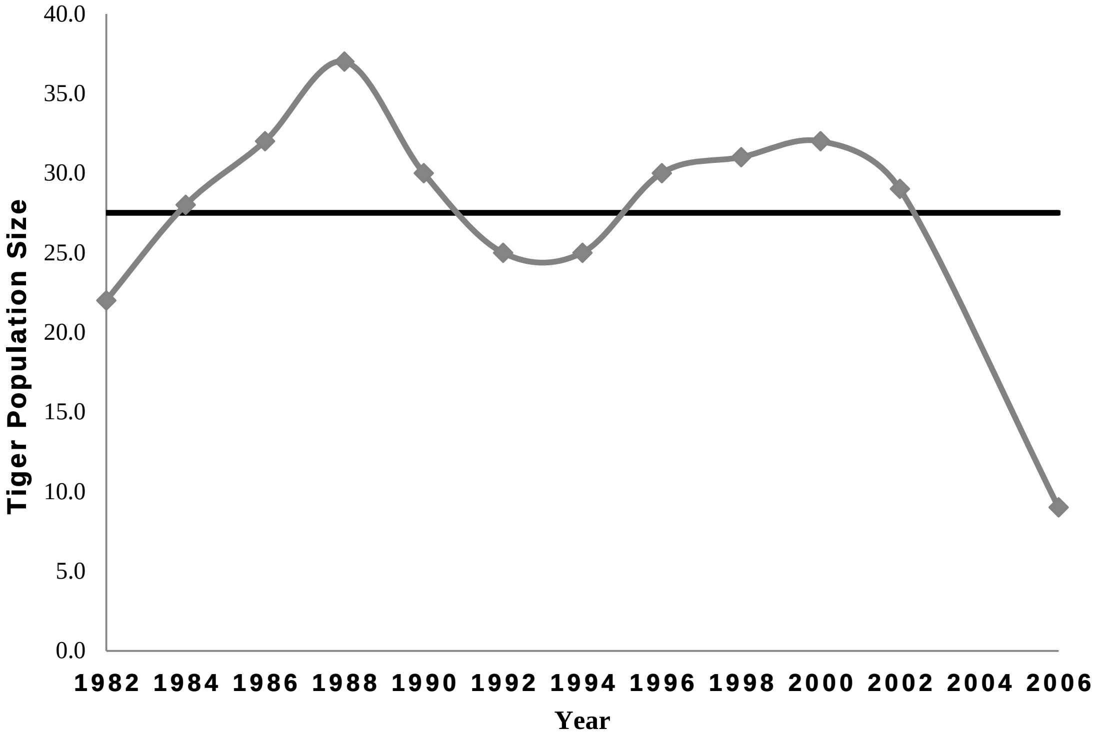
3. low human involvement ($\Rightarrow$ minimum # of touches, easy operation, monitoring & (re)configuration)

Tiger Protection: Panna National Tiger Reserve Story



Tiger Population and Extinction

Above 25 tigers reported in the past



Extinction occurred in February 2009

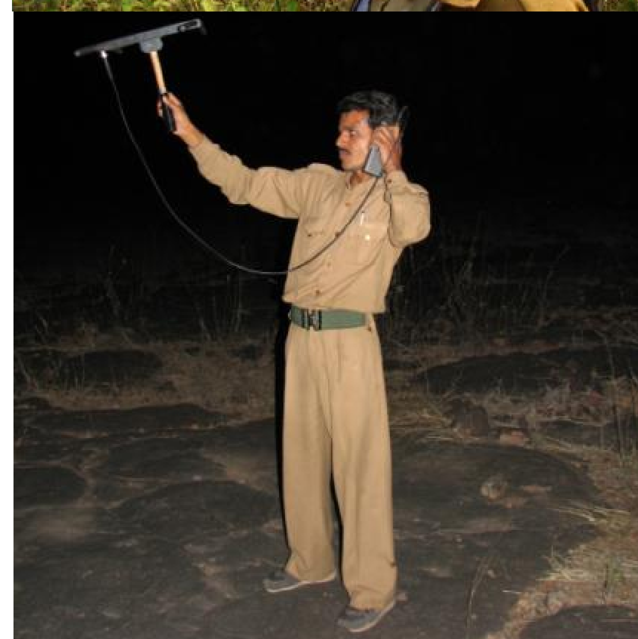
Slide courtesy of K. Ramesh

Tiger Reintroduction

Panna became the site of a very successful tiger translocation

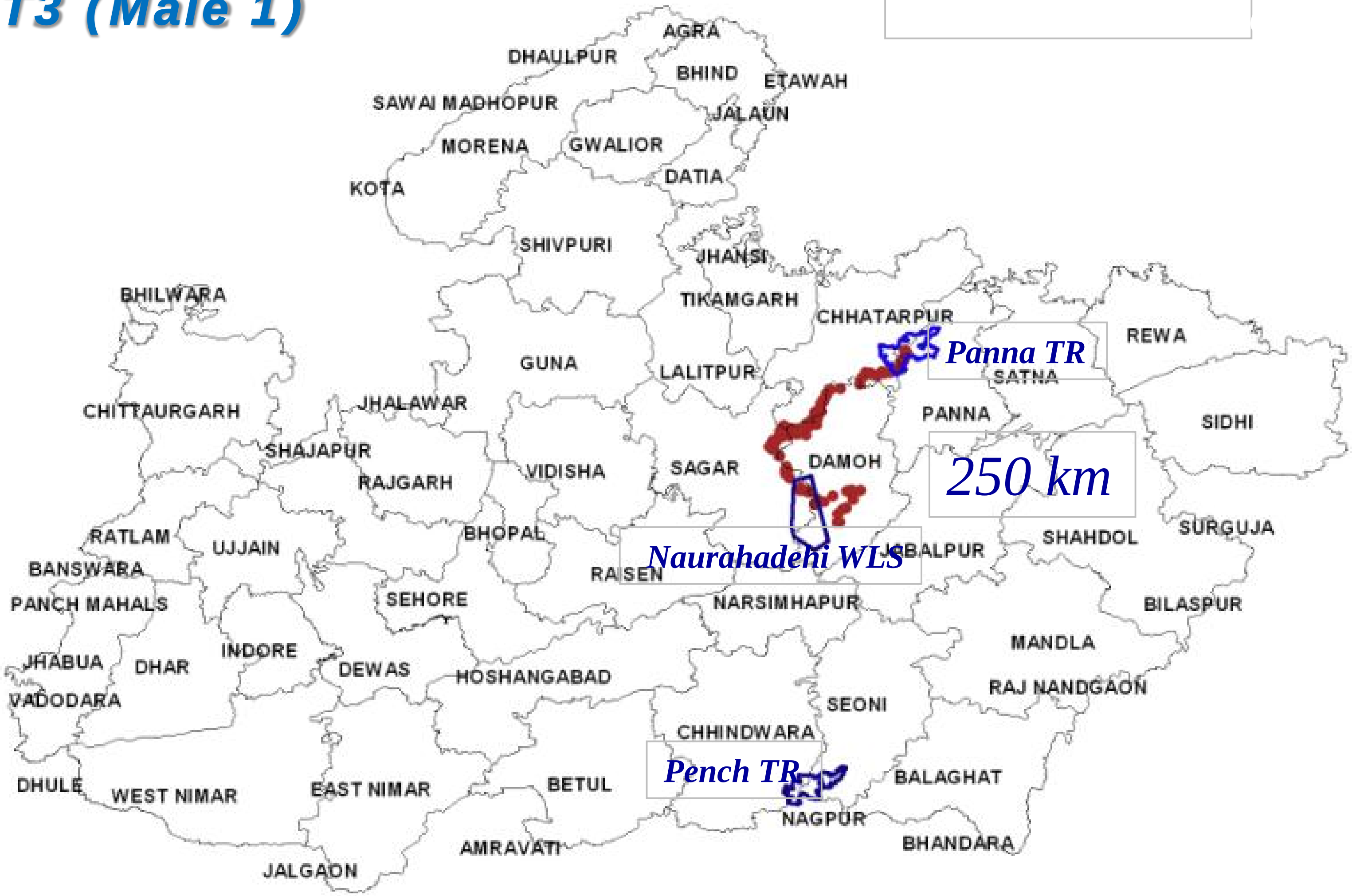
Tigers were brought from nearby reserves in Bandhavgarh, Kanha, and Pench

Tigers were Collared



... and monitored day and night

T3 (Male 1)



Slide courtesy of K. Ramesh

Breeding has Succeeded

Healthy population of 35 tigers today, 3rd generation growing up

Major Challenges Remain: Motivate WSN for Protection

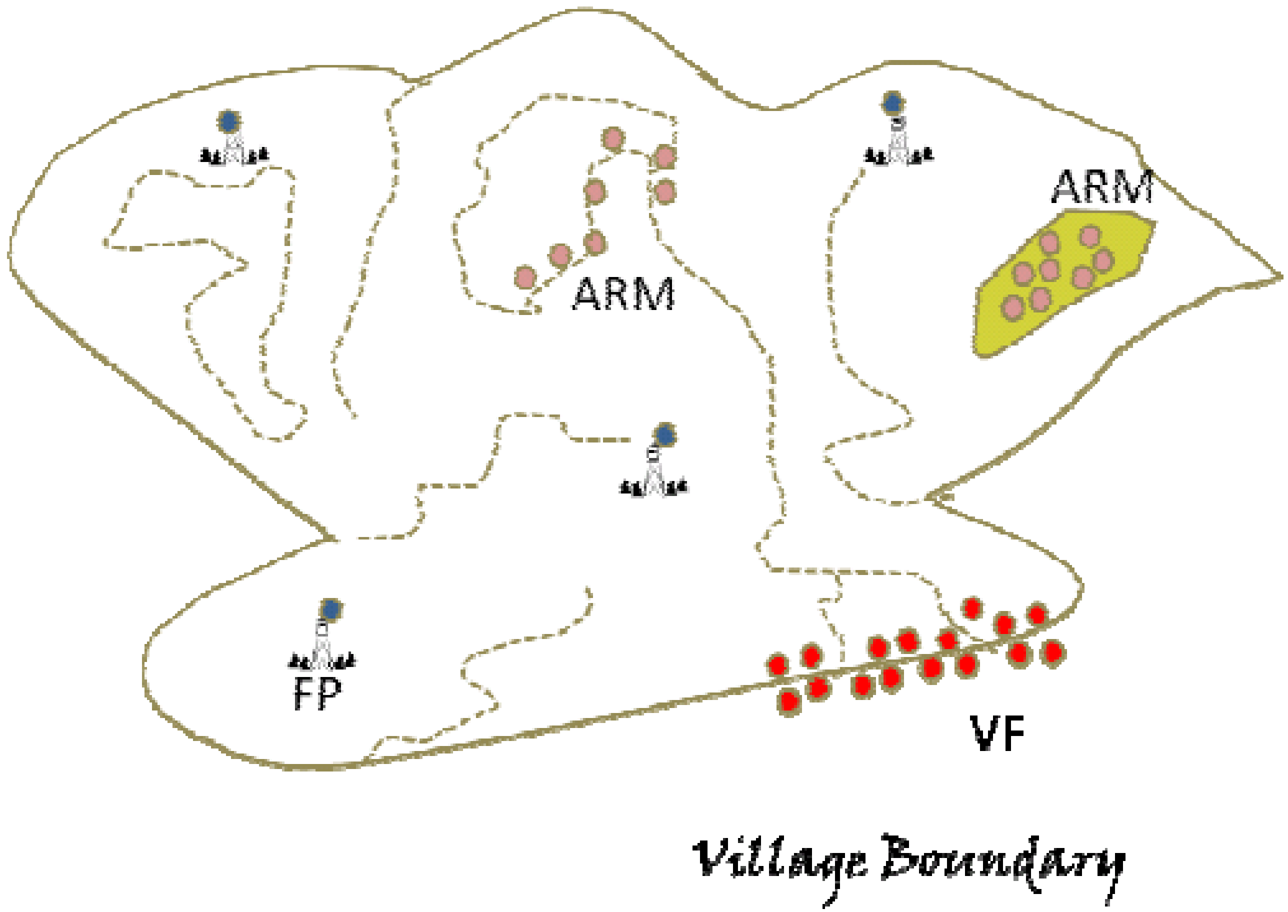
- Human monitoring has been draining, security amplification mechanism needed

- Barely a majority being monitored, threats remain

- Tree felling, fires, etc.

Kardhai Teak patch

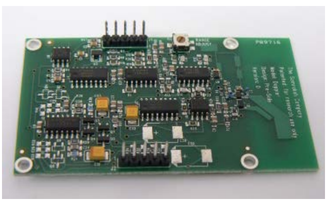
WSN Protection in Panna: Solution Concepts



VF *Virtual Fence*
ARM *Activity Region Monitor*
FP *Field Probe*

Sensors

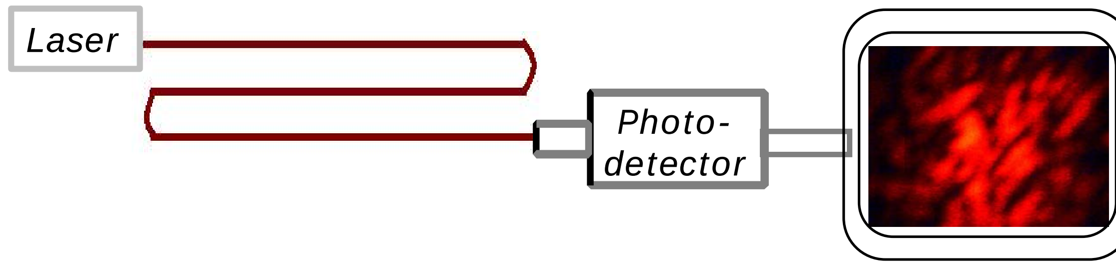
Micropower Impulse Radar



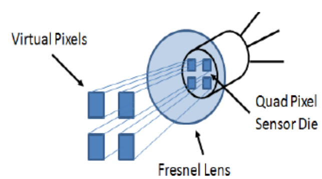
Local Mote-based Detector & Classifier & Counter

Network-based Classifier & Counter

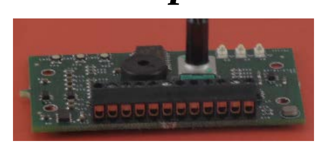
Optical Fiber



Pyro-electric Infrared



Microphone



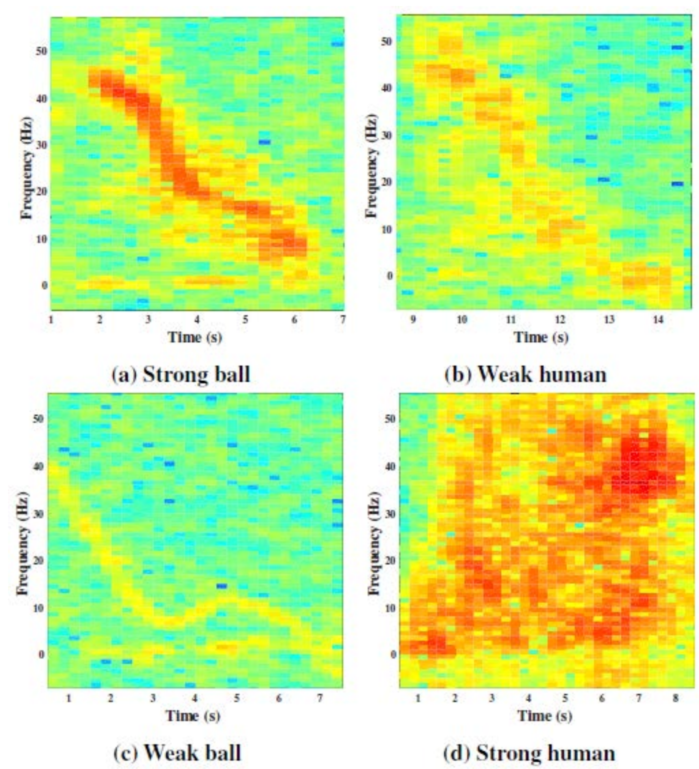
Tiger-Human Classification via Micropower Radar

- Basic approach:
  - use data driven machine learning from rich set of parameterized features
  - reduce complexity by selecting parameters first & then features
  - experimental selection of kernels

- The *target-not-of-interest* challenge:
  - vegetation, small animals, large animals (e.g., Neelgai)
  - current solution:
    - reject in situ movements (vegetation)
    - data driven customization for target-of-interest

Data Driven Issue: Need Enough Data

- To classify targets in diverse environments and clutter, enough training data needed to capture radar return in different “configurations”



(a) Strong ball
(b) Weak human
(c) Weak ball
(d) Strong human

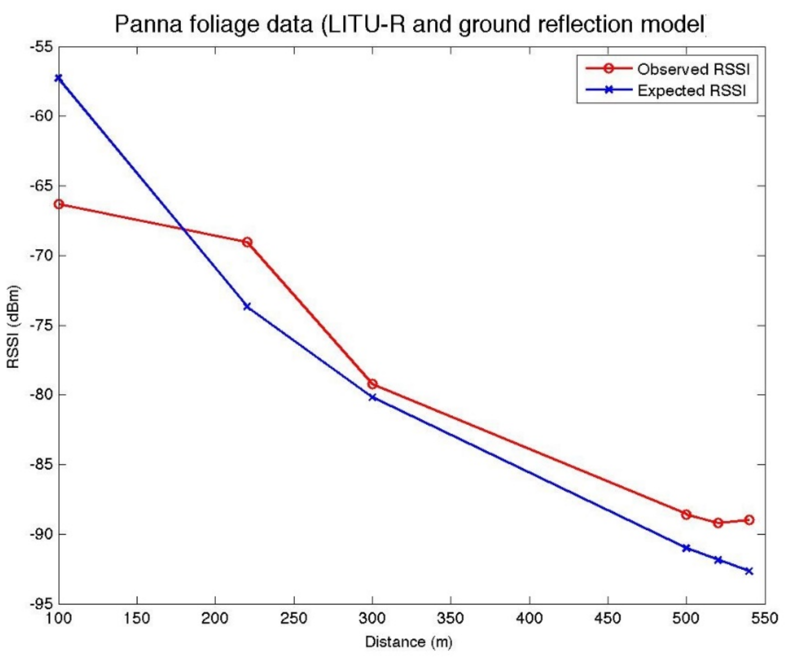
- Solution: Augment data synthetically from data-derived radar response models

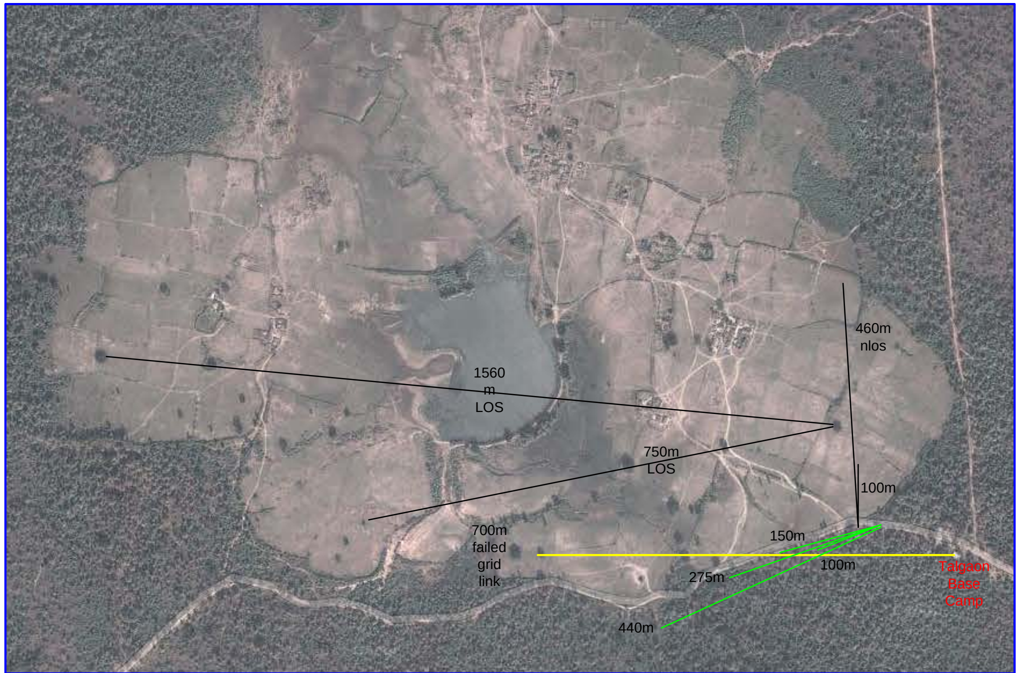
Networking Challenges: Link Variability

Link loss depends substantially on frequency *f*, height *h*, foliage

$$L_{forest}(dB) = Af^B d^C + 40\log(d/h) \quad , \quad \text{where } d \text{ is distance}$$

- 3km open flat terrain link ≈ 500m link dense tree link





Options for Network Robustness

- Lower frequency
  - constrained by available spectrum ☹
- Node height
  - at ~25’, links enabled 3-4 hop network
- Low (adaptive) data rate, packet size

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Applications of WSNs and IoTs...

- ... are of many types:
  - Target Detection, Classification, and Tracking
  - Pursuer Evader Games
  - Habitat Monitoring, Building Monitoring
  - Building / Data Center Control
  - Farm Waste Monitoring, Smart Farming and Irrigation
  - Asset Management
  - mobile Health Monitoring (of Humans, Critical Plants)

Specific Recent Examples

- People counting
- Crowd characterization and crowdsourced truth detection
- Occupancy inference
- Social encounter based path refinement

- Smoking detection
- Stress assessment (see also and this)
- Life pattern detection

- Social sensing (see also)
- Smartphone acoustic recognition (ambience characterization)
- Piggybacked crowd sourcing
- Music selection

- Localization (via UWB) of moving objects from anchors (see also)
- Face to face interaction sensing with RF and ultrasonic
- Localization via social sensing

Specific Examples

- Home power consumption (see also and this)
- Wastewater gas monitoring
- Fixture Finder
- Smart HVAC (see also and this/that on building response modeling)
- Data center power capping

- Taxi dispatch sensing
- Automotive sensing
- Low Power Vehicular Navigation
- Disaster rescue WSN with mobile robots
- Driving detection

- Smart Irrigation
- Structural control

- Drone sensor networks

Assignment 0 (adopted from Ted Herman)

Your assignment is to read and present in class one sensor network application next week, as reported in a published paper. Surf the web to find material complementary to my pointers.

The time for your presentation should be less than 8 minutes; use the model of this powerpoint presentation presentApp.ppt.

Before next Wednesday's class, you'll need to email me your presentation.

Your presentation will let other students know about some sensor network application, so they have an overview without having to read the paper in as much detail as you did.

To prepare the presentation, you likely need'nt master all the details of the paper. Often, though, it can help to find backup technical reports and presentations by the researchers, to help you prepare. Overall, you should spend about four to six hours on this task.

Specific Examples

- Detect submerged targets in a harbor / ocean environment
- Detect chemical or biological attacks
- Detect forest fires
- Detect building fires and set up evacuation routes
- Monitoring dangerous plants
- Monitoring social behavior of animals in farms and natural habitats
- Monitoring salinity of water
- Monitoring cracks in bridges
- Bathymetry of ocean ground
- Space exploration
- Tracking dangerous goods
- Shooter Localization
- Pacemakers for heart and brain
- Camera-equipped pills for health diagnostics
- Epilepsy monitoring and suppression

References for Applications

- Autosense: mobile health [ref]
- In hospital monitoring [ref]
- Building energy sensing [LoCal ref, ref, ref; Residential ref]
- Watershed monitoring [ref]
- Pipeline monitoring [ref, ref]
- Wildlife monitoring [ref]
- Forest sensing [ref greenorbs] ; City sensing [ref
- Autowitness: Stolen car tracking [ref]
- People tracking camera networks [ref]
- Disaster recovery [ref]
- Logistics management [ref]
- Games for teaching computer science [ref]
- Participatory sensing [ref for biker sensing]
- Vehicle classification [ref]

References for Applications

- Hospital Epidemiology: Wireless Applications for Hospital Epidemiology [ref]
- Nericell: Rich Monitoring of Road and Traffic Conditions using Mobile Smartphones [ref]
- Participatory sensing in commerce: Using mobile camera phones to track market price dispersion [ref]
- The BikeNet Mobile Sensing System for Cyclist Experience Mapping [ref]
- Model-Based Monitoring for Early Warning Flood Detection [ref]
- NAWMS: Nonintrusive Autonomous Water Monitoring System [ref]
- Luster: Wireless Sensor Network for Environmental Research [ref]
- Hybrid sensor network for cane-toad monitoring [ref]
- SensorFlock: An Airborne Wireless Sensor Network of Micro-Air Vehicles [ref]
- Identification of Low-Level Point Radiation Sources Using a Sensor Network [ref]

References for Applications

- Mobile Sensor/Actuator Network for Autonomous Animal Control [ref]
- Detecting Walking Gait Impairment with an Ear-worn Sensor [ref]
- Textiles Digital Sensors for Detecting Breathing Frequency [ref]
- Recognizing Soldier Activities in the Field [ref]
- Physical Activity Monitoring for Assisted Living at Home [ref]
- PipeNet: Wireless sensor network for pipeline monitoring [ref]
- Turtles At Risk [ref]
- Cyclists' cellphones help monitor air pollution [ref]
- Clinical monitoring using sensor network technology [ref]
- CargoNet: low-cost micropower sensor node exploiting quasi-passive wakeup for adaptive asychronous monitoring of exceptional events [ref]
- Monitoring persons with parkinson's disease with application to a wireless wearable sensor system [ref]

References for Applications

- Expressive footwear, shoe-integrated wireless sensor network [ref]
- BriMon: a sensor network system for railway bridge monitoring [ref]
- Monitoring Heritage Buildings [ref]
- PermaDAQ: gathering real-time environmental data for high-mountain permafrost [ref]
- Firewxnet: a multi-tiered portable wireless for monitoring weather conditions in wildland fire environments [ref]
- Development of an in-vivo active pressure monitoring system [ref]
- Personal assistive system for neuropathy [ref]
- Smart jacket design for neonatal monitoring with wearable sensors [ref]

References for Applications

- Condition Monitoring in Intel Hillsboro Fabrication Plant
  - or BP's Loch Rannoch Oil Tanker [ref]
- Other BP applications (safety, corrosion detection, empty propane tanks)
- Volcano Monitoring
- Seismic Monitoring
- Landslide Detection
- Water Distribution Monitoring and Control (agricultural and sewer)
- Water Quality
- Water Sense
- Lake (Aquatic organism) Monitoring
- Cane Toad Monitoring
- Neptune Ocean Observatory [ref]
- Atmospheric Observatory [ref]
- Neon (scope and canonical experiments)

References for Applications

- SensorScope
- SenseWeb
- CarTel [ref]
- Odor Source Localization
- CodeBlue (Health care)
- Activity Recognition [ref]
- Assisted Living [ref]
- Wearable wireless body area networks (Health care)
- Adaptive house
- PlaceLab and House_n projects
- Participatory Sensing
- Responsive Environments (Uberbadge)
- Lover's cup context aware

References for Applications

- SensorWebs in the Wild
- Dynamic Virtual Fences for Controlling Cows
- Hardware design experiences in ZebraNet
  - Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet (see also additional background & Zebranet Web Site)
- Sensor/actuator networks in an agricultural application (you'll need to search for more on this topic)
  - http://www.tde.lth.se/cccd/images/CCCD%20Workshop%202004-JMadsen.pdf
  - www.diku.dk/users/bonnet/papers/PhB-Kuusamu.ppt
- Smart-Tag Based Data Dissemination
- Sensor network-based countersniper system
- A large scale habitat monitoring application
  - Wireless Sensor Networks for Habitat Monitoring.
  - Habitat Monitoring: Application Driver for Wireless Communications Technology.
  - Preprocessing in a Tiered Sensor Network for Habitat Monitoring
  - Wireless Sensor Networks for Habitat Monitoring
  - Additional Sensor Network Project Sites: Coastal Observatory, Santa Margherita Reserve, Rockwell: Surveillance, Great Duck Island

References for Applications

- Dynamic Networking and Smart Sensing Enable Next-Generation Landmines
- Flock Control
    - Adaptive Sampling Algorithms for Multiple Autonomous Underwater Vehicles, *Proceedings IEEE Autonomous Underwater Vehicles Workshop Proceedings, S*ebasco, ME, June, 2004
- Sensor Web for In Situ Exploration of Gaseous Biosignatures
- Active visitor guidance system (follow the single reference, using Google, to find more)
- Two-Tiered Wireless Sensor Network Architecture for Structural Health Monitoring
    - Sensor-actuator network for damage detection in civil structures
- Meteorology and Hydrology in Yosemite National Park: A Sensor Network Application.
- A Survey of Research on Context-Aware Homes.
    - The Aware Home: A Living Laboratory for Ubiquitous Computing Research
    - Using Pervasive Computing to Deliver Elder Care
- Workplace Applications of Sensor Networks
- Cougar Project at Cornell (student projects, which have some slides about a demo)
- Contaminant Transport Monitoring
- Marine Microorganisms (Adaptive Sampling for Marine Microorganism Monitoring)
- A Support Infrastructure for the Smart Kindergarten

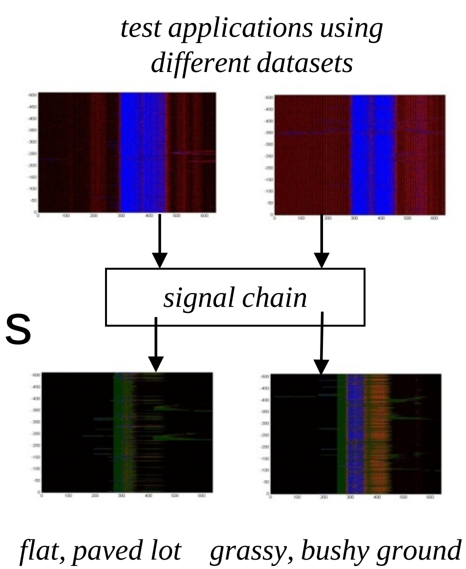
Kansei Roles (I)

Validate systems at-scale

- multi-array applications
- debugging
- predictable performance

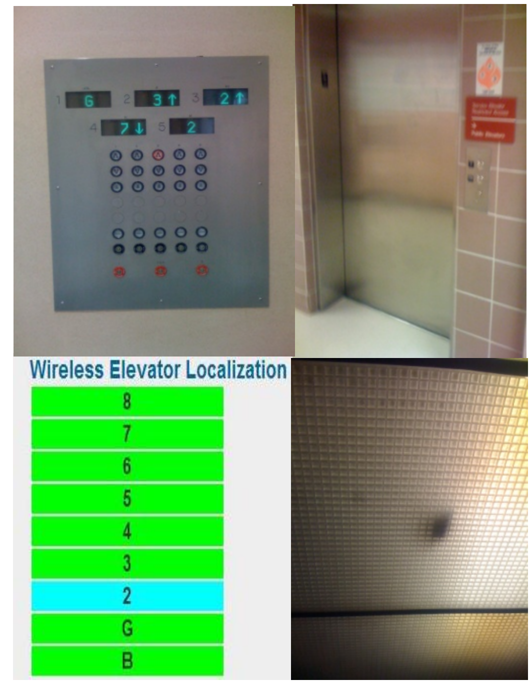
Regression testing

- injecting different sensor datasets
- compare performance of algorithms



Modeling, discovery of phenomena

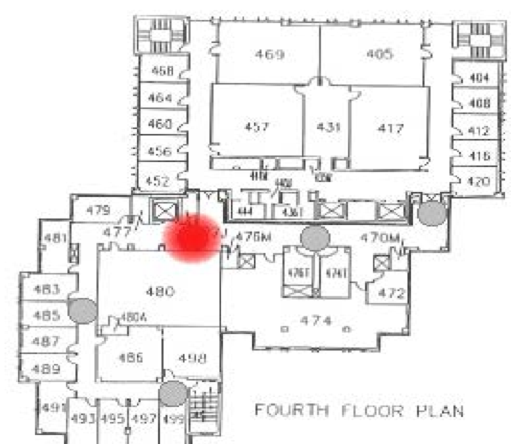
Kansei Roles (II)



Location-specific sensing

People-centric networking apps

- Mobility testbed
- Mobile sensing (planned): NO_X,CO



Kansei Roles (III)

Experimentation/application interaction services

- code deployment
- scheduling
- health
- injection, exfiltration
- frequency, key management

Integrated development environment

- diverse object, source, and high-level language input
- tools for visualization, simulation, etc.

Outline

- Anatomy of a wireless sensor network (WSN)
- Brief overview of some application contexts: Project *ExScal* and *Tiger Protection*
- More on application contexts
- Anatomy of a MANET
- State-of-the art MANETs

MANET: Mobile Ad Hoc Networks (MANET)

- Acronym soup:

UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UUV	Unmanned Underwater Vehicle
AUV	Autonomous Underwater Vehicle
MAV	Micro Aerial Vehicle
GR	Ground Radio

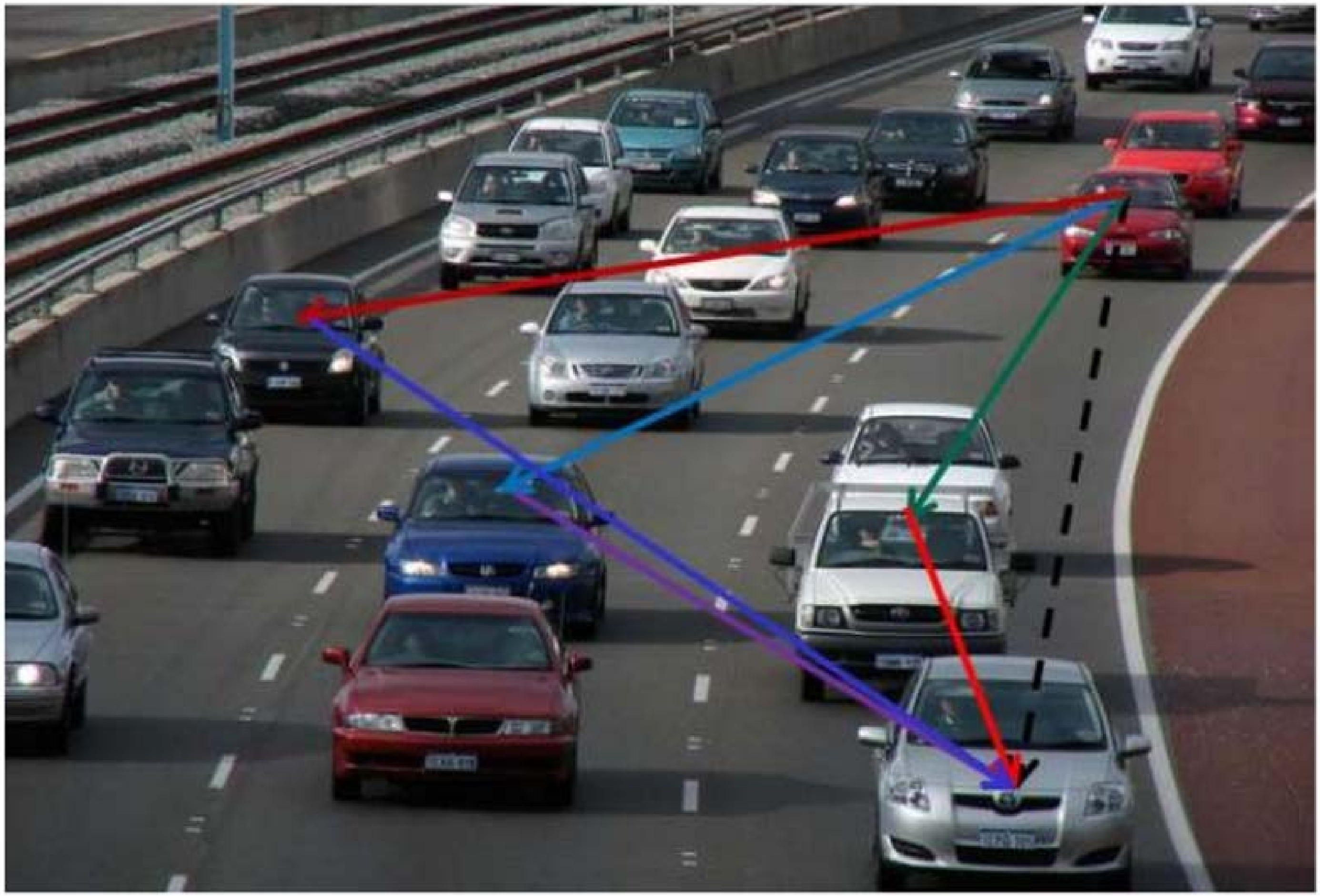
- Hierarchy of networks is challenging to maintain
  - Mobility implies high overhead coordination, network still often disconnected for subtle reasons (of convergence time and stability)

Diverse MANET devices

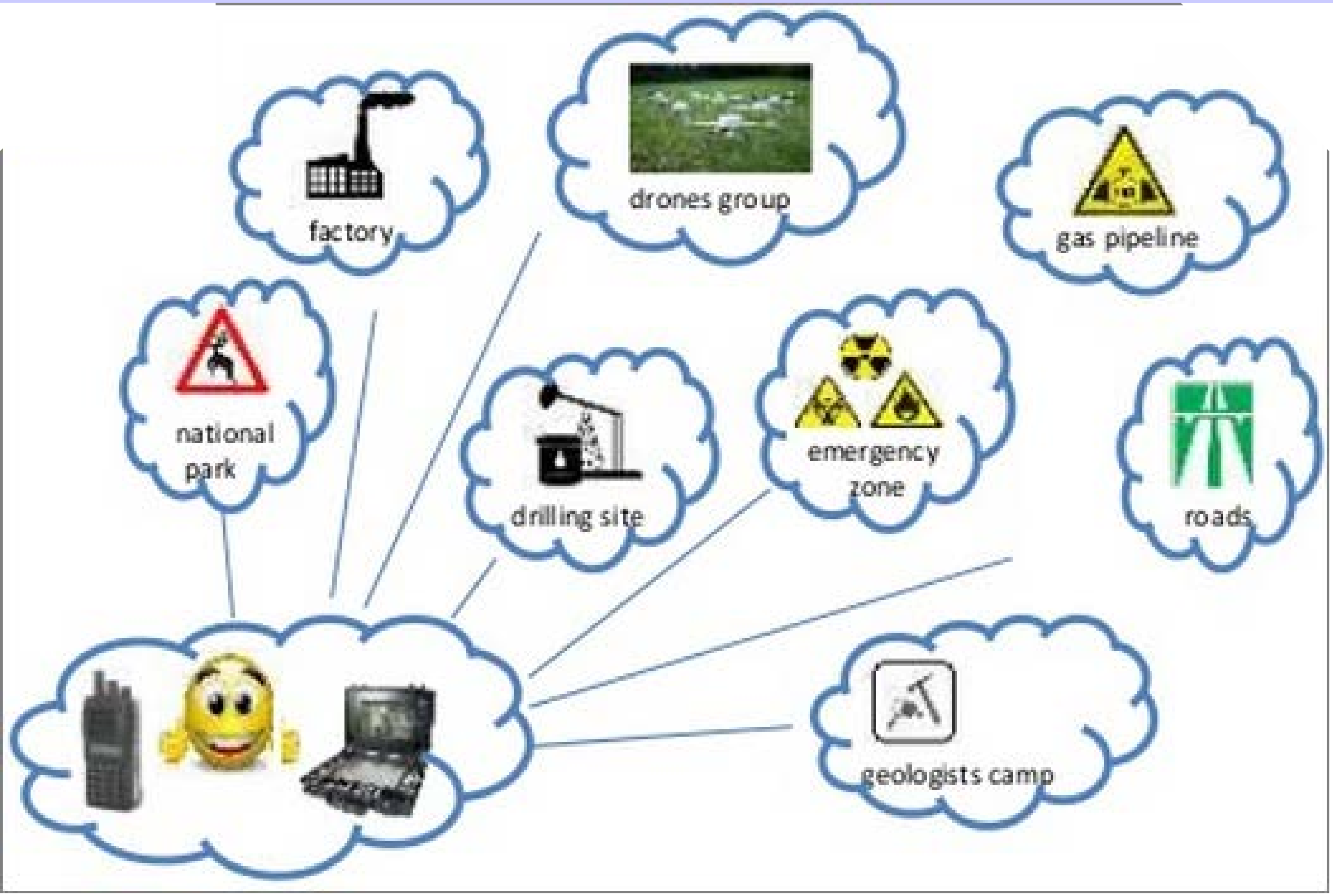
Nodes tend to be diverse and heterogeneous

- radios: variety of power, comm rate, comm range
- sensors: high res camera, hyperspectral imager, radar, lidar
- mobility: speed, height, range, weight, lifetime

Includes VANET if not infrastructure based



Applications trending from DoD to commercial



precision agr.

counting animal (nest)

mapping habitats, forests, logging, carbon / nitrogen capacity

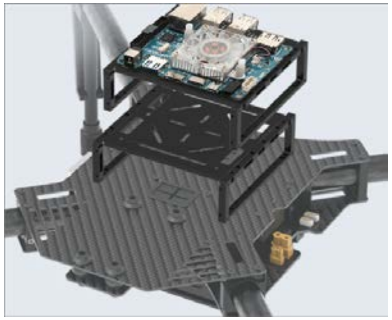
- Commercial drones lower cost, easier to program, mission plan, deploy, and fly, & better supported for data integration

Drone platforms becoming more open

- DJI Matrice 100

3D Robotics

- Can add mote
- Can add sensors



Linux based
Can hack to
integrate sensor
Phone coupled