As presented at NIKSUN WWSMC

July 25-27, 2011 | www.niksun.com

ON SECURITY-ENERGY TRADEOFFS AND COOPERATION FOR WIRELESS AD HOC NETWORKS

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A Different Perspective on Security for Wireless

- Security is a key requirement for wireless communications
- Energy is also a key performance metric
- Typically security and energy are treated as separate topics
- A different perspective: security and energy are inter-related
  - Security assurance mechanisms are usually energy hungry
  - Some types of attacks may lead to depleted battery for individual nodes

SECURITY-ENERGY TRADEOFFS

- Security mechanism often put a high toll on energy resources, as they may require extensive data acquisition, complex processing algorithms or/and substantial overhead for coordination.

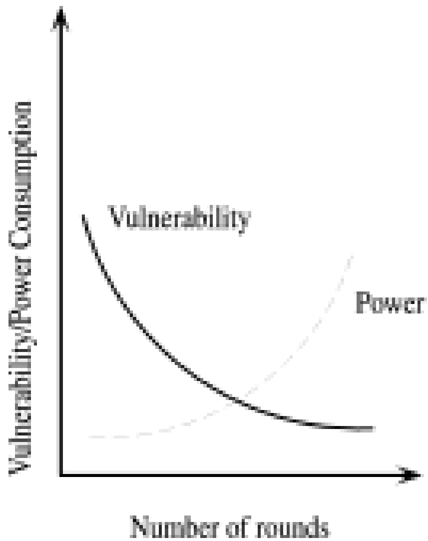
- **Some Examples:**
  - Encryption – Algorithms – shown to consume a significant portion of a terminal's battery (early work[Krishnamurthy et all, 2001]: 600 encryption operations for triple-DES reduces the battery availability to 45%)
  - Intrusion Detection Systems (IDSs) – require gathering, and complex analysis of substantial amounts of data
  - Physical Layer Security – requires additional transmissions for friendly jammers to mask the useful transmission

How to characterize security-energy tradeoffs

- Need to measure “the amount of security you get” for the “price of energy spent”
- **Security Gains** – related to classic performance metrics, such as:
  - IDSs – probability of miss detection
  - Encryption – resilience to cryptanalysis attacks.
  - Physical layer security – secrecy capacity
- **Energy Costs** – The amount of energy spent to obtain the security gains

❖ Typically characterized by measurements + Some model fitting for specific security applications

Examples for Energy-Security Tradeoffs – Analytical Models - Encryption

- [Chandramouli & all, 2006] –characterizes the power battery consumption for encrypting using various block cipher algorithms
- 

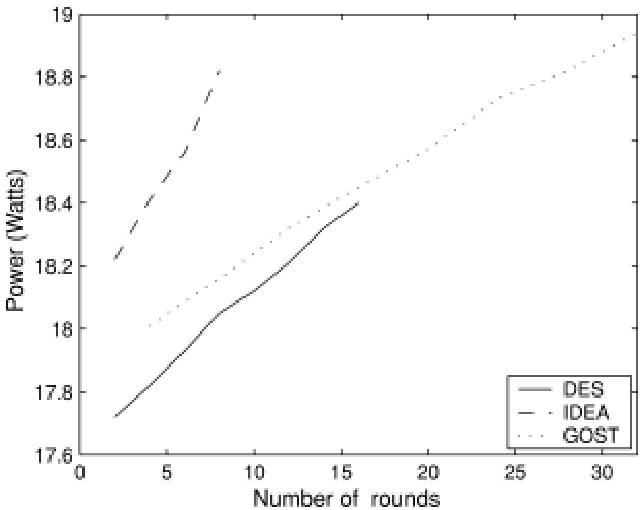


Fig. 4. Power consumption for different rounds of DES, IDEA, and GOST.

  - Linear regression:
    - $P(r) = 0.0486r + 17.7335$ *DES*
    - $P(r) = 0.0975r + 18.015$ *IDEA*
    - $P(r) = 0.03321r + 17.90204$ *GOST*

Examples for Energy-Security Tradeoffs – Analytical Models – Intrusion Detection

- Security application: detect anomalous traffic behavior in the network using IDS – **security performance metric: probability of detection**

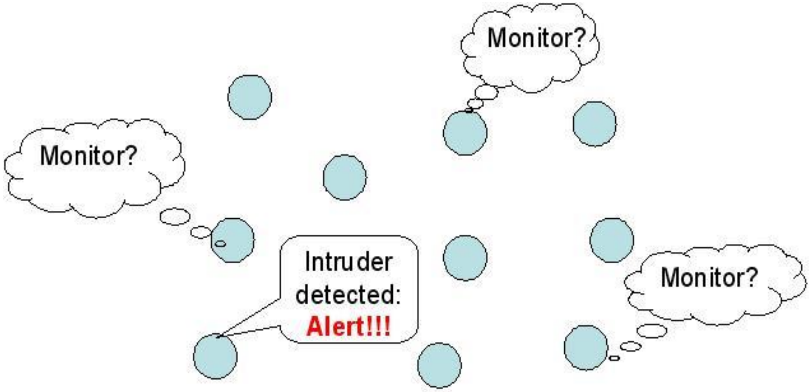
- **Energy Utility:** [Futaci, Runser, Comaniciu, 2008] extends and validates work in [Sinha et all, 2001]
  - measurements on the Freescale Semiconductor MC9S08GT60 Microcontroller (typical for a wireless ad hoc node) → ***first order approximation formula for energy expenditure as a function of algorithm complexity***

$$E_{TOT} = V_{DD} \cdot I_0(Vdd, f).\frac{t(n).N.c}{f}$$

  - Energy depends on:
    - supply voltage and current,
    - *t(n)* - time complexity function giving the total step count*, n* is the instance characteristic,
    - *N*- average number of machine instructions per step count*,*
    - *c* - average number of machine cycles per machine language instruction
    - *f* is the operation frequency of the computing platform.

COOPERATION FOR IMPROVING THE ENERGY-SECURITY TRADEOFFS

- Take advantage of the network structure – a sufficiently dense network may “time-share” the security duties



Monitor?? → lose energy
Not monitor??? → possible attack, but maybe somebody else will monitor?!

- Challenges:
  - Implement distributed algorithms – nodes take decisions independently with no centralized infrastructure
  - Potentially selfish nodes: “Tragedy of the commons” – everybody would like to benefit, no one would like to pay the price – a classic game theoretic problem formulation – Incentivize cooperation?
  - Selfish versus malicious nodes – ensure that cooperation is among trusted nodes, or/and security algorithms (e.g. IDS) are robust to malicious behavior.

Distributed Intrusion Detection System (IDS)

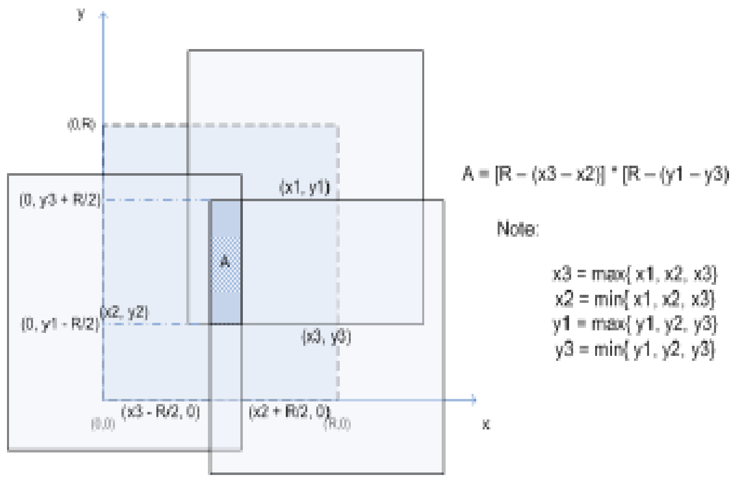
- Requirements:
  - Independent decisions based on local information
    - Monitor, not monitor, or type of monitoring algorithm employed
  - Local convergence to a given network operating point
  - Game Theoretic Modeling – useful analysis tool
    - Players: nodes in a network neighborhood
    - Actions (Strategies): nodes' monitoring decisions
    - Objective for individual nodes: maximize their individual utility (security gains – monitoring costs)
    - **Nash equilibrium** – the convergence point of the distributed algorithm → no player has incentive to unilaterally deviate

An Example IDS for Wireless Sentinel Networks

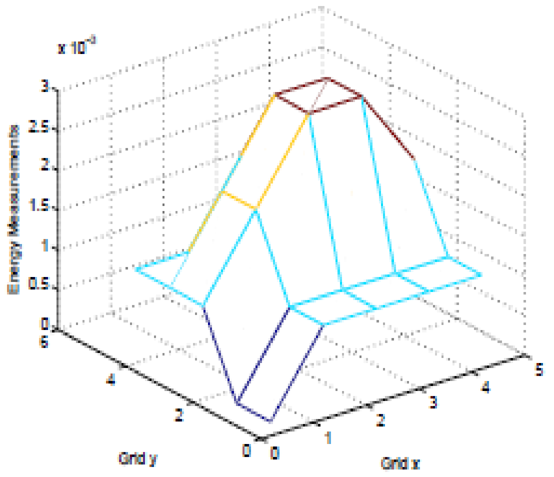
- Security application – wireless sentinel networks – monitor for illicit wireless transmissions in a network neighborhood (with or without ongoing legitimate traffic).
- No knowledge about the transmission waveforms of the intruder → energy detector
- Multiple nodes report estimated energy levels – soft information
- Access point aggregates reports - exploits diversity – MRC for overlapped sensing regions → builds 3D likelihood map
- Detection based on threshold – fixed probability of false alarm

COOPERATION BENEFITS

- Multiuser diversity enhances the detection accuracy
- Localization area → multiple reports with overlapped sensing regions
- Energy requirements reduced by "time-sharing" the monitoring load.



(a) Illustration of three reports



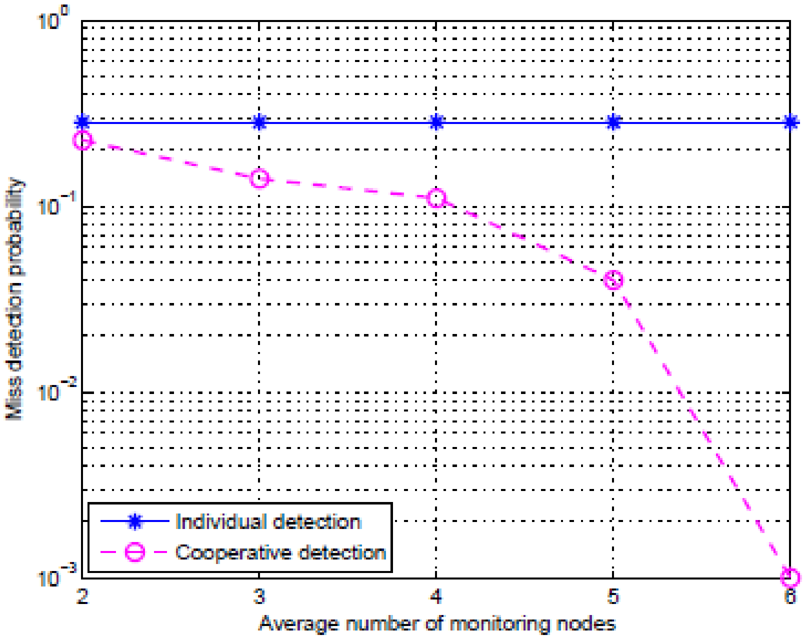
(b) Illustration of 3D energy distribution map

QUESTIONS TO BE ANSWERED

- Optimal strategy for nodes ?
- Existence of Nash equilibrium ?
- Cooperation gains ?
- As a finite game a MIXED STRATEGY NASH Equilibrium is guaranteed to exist → nodes will monitor with an equilibrium probability p_M
  - Indifference principle: determined such that the average utility for monitoring = average utility for not monitoring.
- Game can be formulated as a
  - **Strategic form game** – we know that the intruder is present in the system (complete information), or
  - **Bayesian game** (static or dynamic) – we believe that the intruder might be present in the system (incomplete information)
  - The cost and utility definitions determine the operating point (NE) of the network

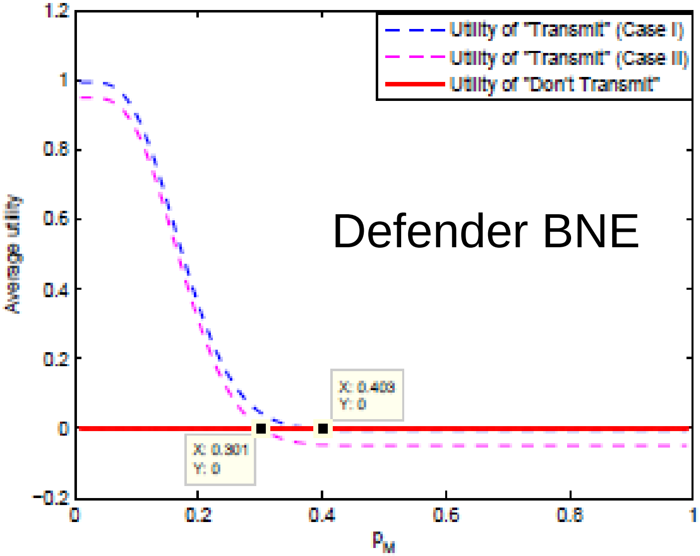
Cooperation gains – A Nash Equilibrium analysis

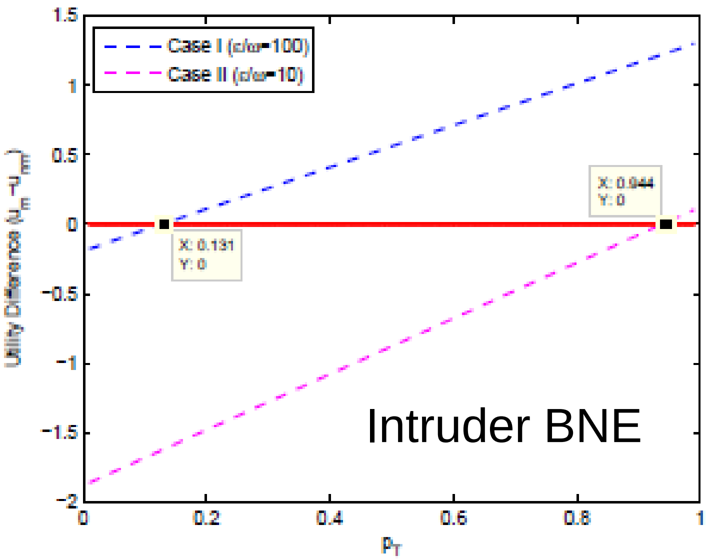
- **Cooperative detection** – a form of MRC for individual energy readings – **multiuser diversity gains**
- **Energy gains** = [energy required for monitoring × (1-probability of monitoring) - collision resolution energy](multiple reports may collide)



Network Operating points – Mechanism design

- Energy and security cost functions can be weighted by price functions
  - Security value: ε
  - Price per unit energy consumption: ω
  - ε/ω defines the relative importance of security and energy – can change the NE solution





Concluding Remarks

- Energy-Security Tradeoffs can be found that characterize security choices for individual nodes
- Cooperation – provides better energy-security tradeoff curves for individual nodes.
- Cooperative security assurance algorithms – another form of exploiting multiuser diversity in wireless networks
- Current research on security-energy tradeoffs still in its infancy - Many intriguing open problems remain to be solved for practical implementations

QUESTIONS ?

Thank you!