SSTIC 2006

Mécanismes de sécurité et de coopération entre nœuds d'un réseaux mobile ad hoc

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Situated and Autonomic Communications
FET Integrated Project CASCADAS (www.cascadas-project.org)

Outline

- Trust in MANET
- Cooperation enforcement
- CORE
  - Sketch of the protocol
  - Simulations
- Analytical validation
  - Application of game theory

Trust in MANET

- Managed environment
  - A-priori trust
  - Entity authentication → correct operation
  - But:
    requirement for authentication infrastructure

- Open environment
  - No a-priori trust
  - Authentication does not guarantee correct operation
  - *New security paradigm*

Threats in MANET

Passive: Selfish Nodes

- Do not cooperate
- Priority: battery saving
- No intentional damage to other nodes
- **Exposure:**
  - Selfish forwarding
  - Selfish routing

Active: Malicious Nodes

- Goal: damage other nodes
- Battery saving is not a priority
- **Exposure:**
  - Denial of service
  - Traffic subversion
  - Attacks on vulnerable mechanisms
  - …

MANET Requirements

- Wireless & Mobile
  - Limited energy
  - Lack of physical security
- Ad hoc
  - No infrastructure
  - Lack of organization

- Cooperation enforcement
- Secure Routing
- Key Management

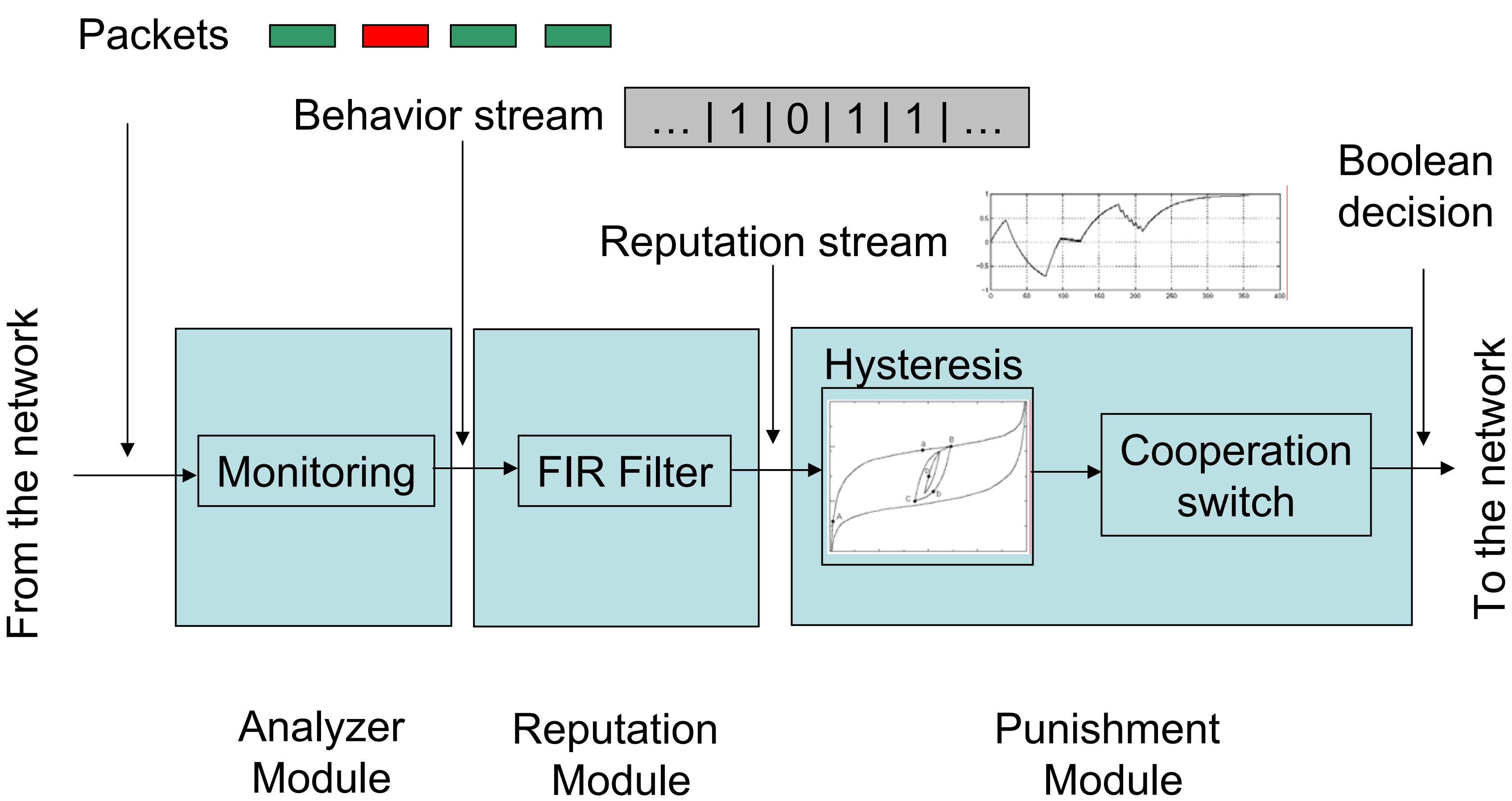
Cooperation Enforcement in MANET

- Routing and Packet Forwarding cost energy
- Selfish nodes save energy for self-interested purposes
- Without any incentive for cooperation network performance can be severely degraded

Cooperation Enforcement in MANET

- CORE: reputation based cooperation enforcement
- Key idea: bind network utilization and reputation metric
- Reputation not used as additional metric for routing
- Other approaches:
  - credit based systems (micro payment)
  - token based systems (threshold cryptography)
  - Mitigating routing misbehavior (reputation as routing metric)

Sketch of CORE



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CORE Components

- Analyzer Module
  - Based on the watchdog (WD) technique
  - Extension: variation of the WD frequency based on local reputation
- Reputation Module
  - Subjective, Indirect (optional) and Functional reputation values are combined with dynamic weights
  - Reputation algorithm:
    - FIR *B*-order filter: initially low-pass, can be more complex (“signatures")
    - Sliding-window of size *B*
- Punishment Module
  - Packets from selfish sources are dropped (deals also with selective misbehavior)
  - Alternatives:
    - Path rater technique, BUT additional node re-integration mechanism
    - Cross-layer punishment: restrict application capabilities (P2P query limits)

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Validation of CORE

- Difficulty raised by reputation-based mechanism

- Our approaches:
  - Simulation-based validation
    - ⇨ Proof of concept
    - ⇨ Realistic measurements: energy, traffic, …

  - Analytical model of MANET and node behavior
    - ⇨ Realistic model of selfishness
    - ⇨ Infer incentive-compatibility properties of CORE

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Simulation-based validation

- Simulation set-up
  - Static and Dynamic Network
    - Random waypoint model (no 0 m/s!)
  - Parameters
    - Pause time, % of selfish nodes, “path diversity”
- Simulation metrics
  - Energy consumption
  - Punishment efficiency
  - False positives
- Basic CORE implementation
  - Monitoring active only for packet forwarding
  - No reputation information distribution: no control traffic overhead
- Selfishness models
  - Selfish nodes systematically fail to forward packets

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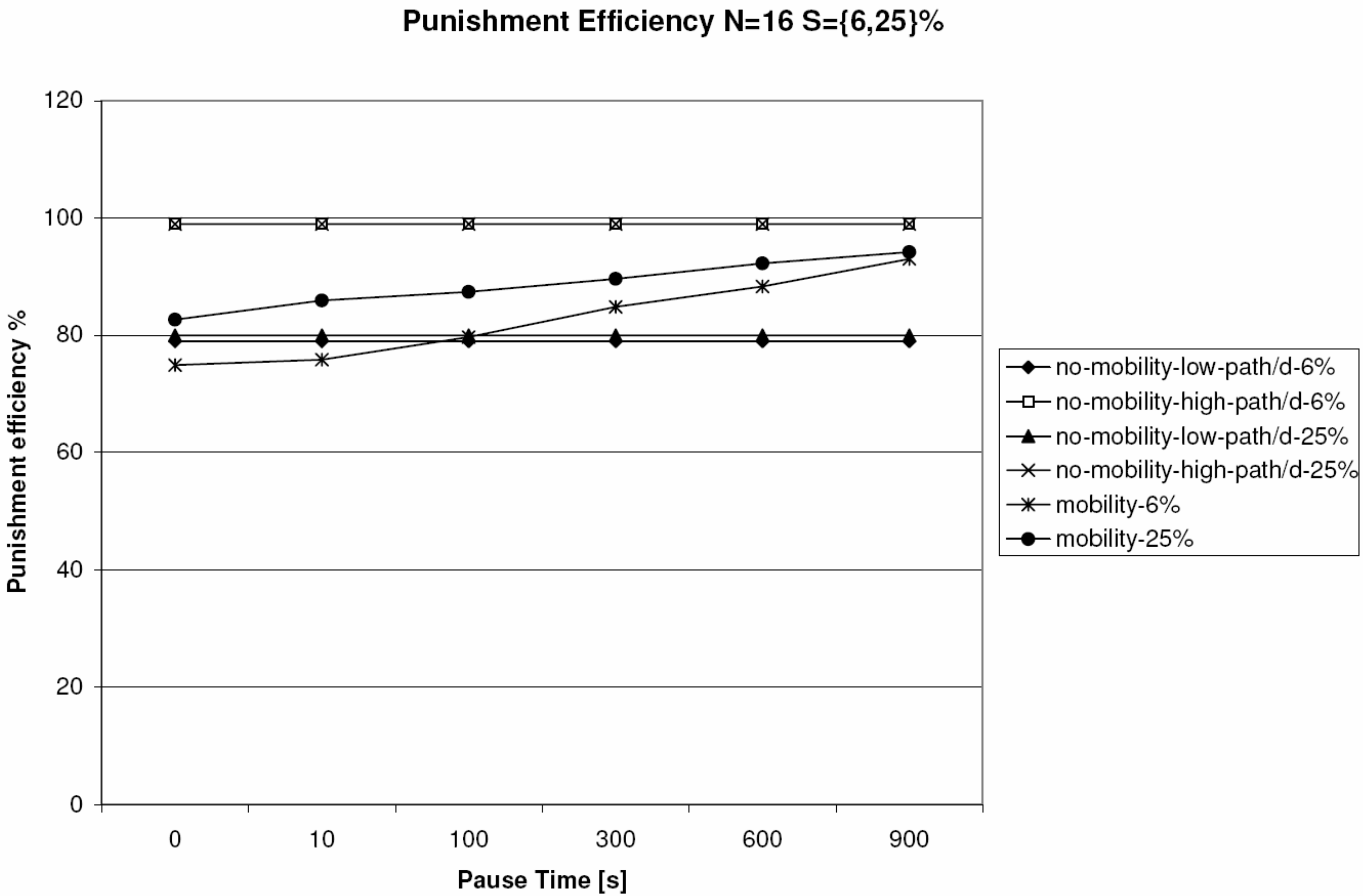
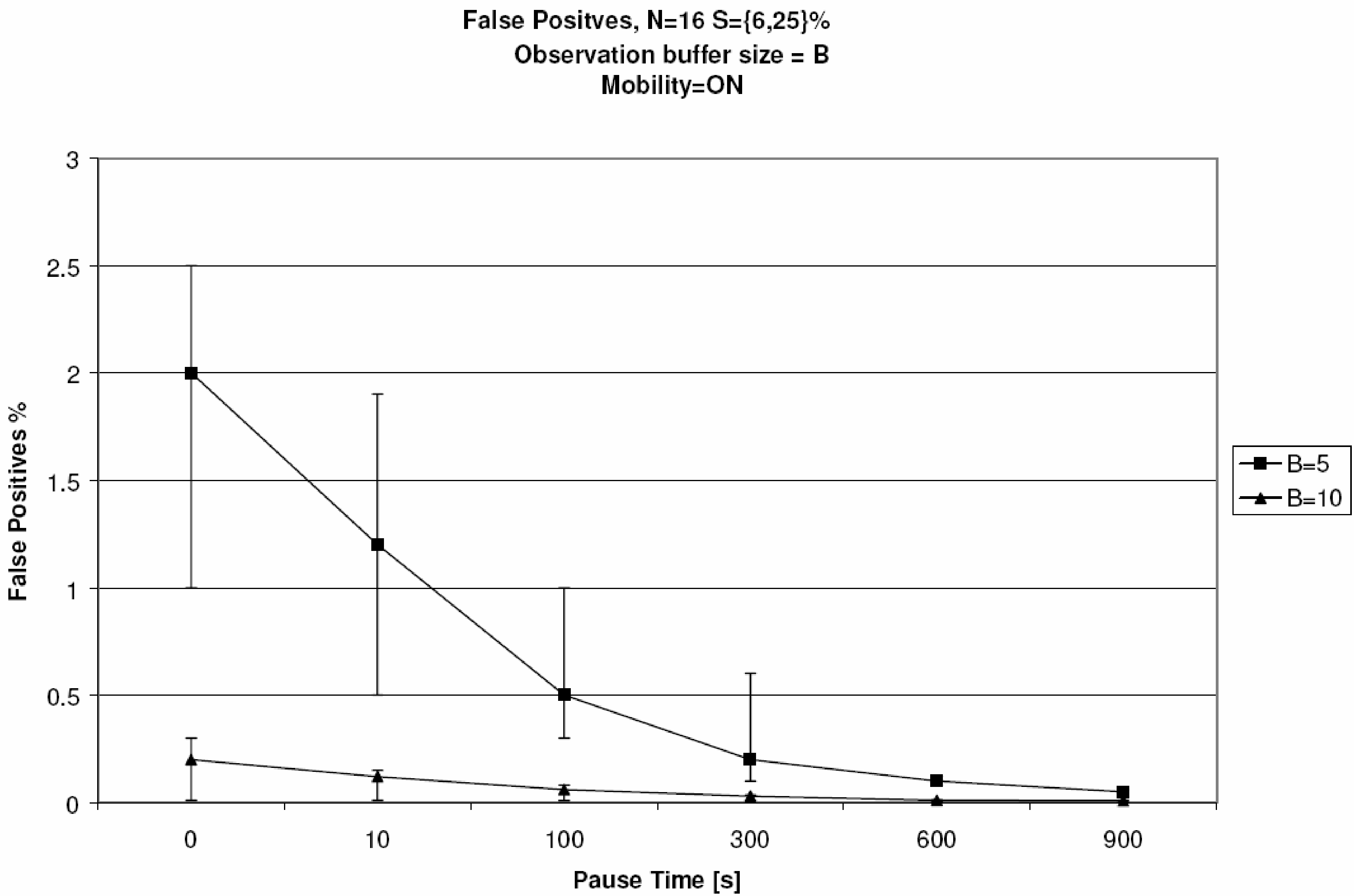
Simulation results

- CORE-enabled legitimate nodes save up to 24% of energy ⇨ legitimate nodes are better off using CORE
- Punishment efficiency ranges from 80% to 100%, WITHOUT reputation distribution ⇨ selfish nodes have strong incentive to cooperate if they want to use the network
  - Distributing reputation is worthless and unreliable
  - Further improvements possible using multi-path routing
- False positives are reasonably low
  - Simple example: reputation algorithm = sliding-window of size *B*, doubling *B* cuts by order of 10 false positives (from 2% to 0.2%)


Punishment Efficiency N=16 S={6,25}%
120
100
80
60
40
20
0
Punishment efficiency %
0
10
100
300
600
900
Pause Time [s]
no-mobility-low-path/d-6%
no-mobility-high-path/d-6%
no-mobility-low-path/d-25%
no-mobility-high-path/d-25%
mobility-6%
mobility-25%


False Positves, N=16 S={6,25}%
Observation buffer size = B
Mobility=ON
False Positives %
3
2.5
2
1.5
1
0.5
0
0
10
100
300
600
900
Pause Time [s]
B=5
B=10

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Limitation of network simulation

- Selfishness models are STATIC
  - Also in related work!
- Need for analytical framework to model DYNAMIC selfish behavior
- Game theory offers tools to model *strategic interaction* among *rational* selfish players

Game Theoretical Validation

- Basic model: non-cooperative game theory
- Packet forwarding as a Prisoner's Dilemma:
  - Players: random pair in the set {1,…,N} nodes of the network
  - Strategy: {C, D} / C=forward, D=drop packet
  - Payoff matrix ≡ utility function (example)

	Player j	
Player i	**Cooperate**	**Defect**
Cooperate	(3,3)	(-2,4)
Defect	(4,-2)	(-1,-1)

Repeated game theory

- Fine-grained modeling of CORE's reputation algorithm through iterated games
  - Players do not know when the game will end
  - SHADOW OF THE FUTURE
- Important extension to the basic model
  - Representation of MAC layer failures (interference, collisions, etc.) that affect the *watchdog mechanism*
- Comparison with alternative strategies:
  tit-for-tat (TFT), generous TFT (G-TFT), spiteful, gradual, …

Evolutionary game theory

- Numerical validation to study robust and stable cooperation strategy (Genetic Algorithms Approach)
  - START: equal partitioning of population into each competing strategy
  - ITERATION: round robin tournament
    Population of bad strategies is decreased whereas good strategies obtain new elements
  - END: population is stable

- Perfect vs. Imperfect private monitoring
  - *Misperception noise* used to model ***watchdog mechanism failures***

Results

- With perfect monitoring
  - CORE and Tit-For-Tat are in equilibrium
- With imperfect monitoring
  - CORE outperforms other strategies because of ***reputation***
    - TFT, G-TFT unstable due to errors
    - Reputation buffer (B) size directly proportional to convergence speed

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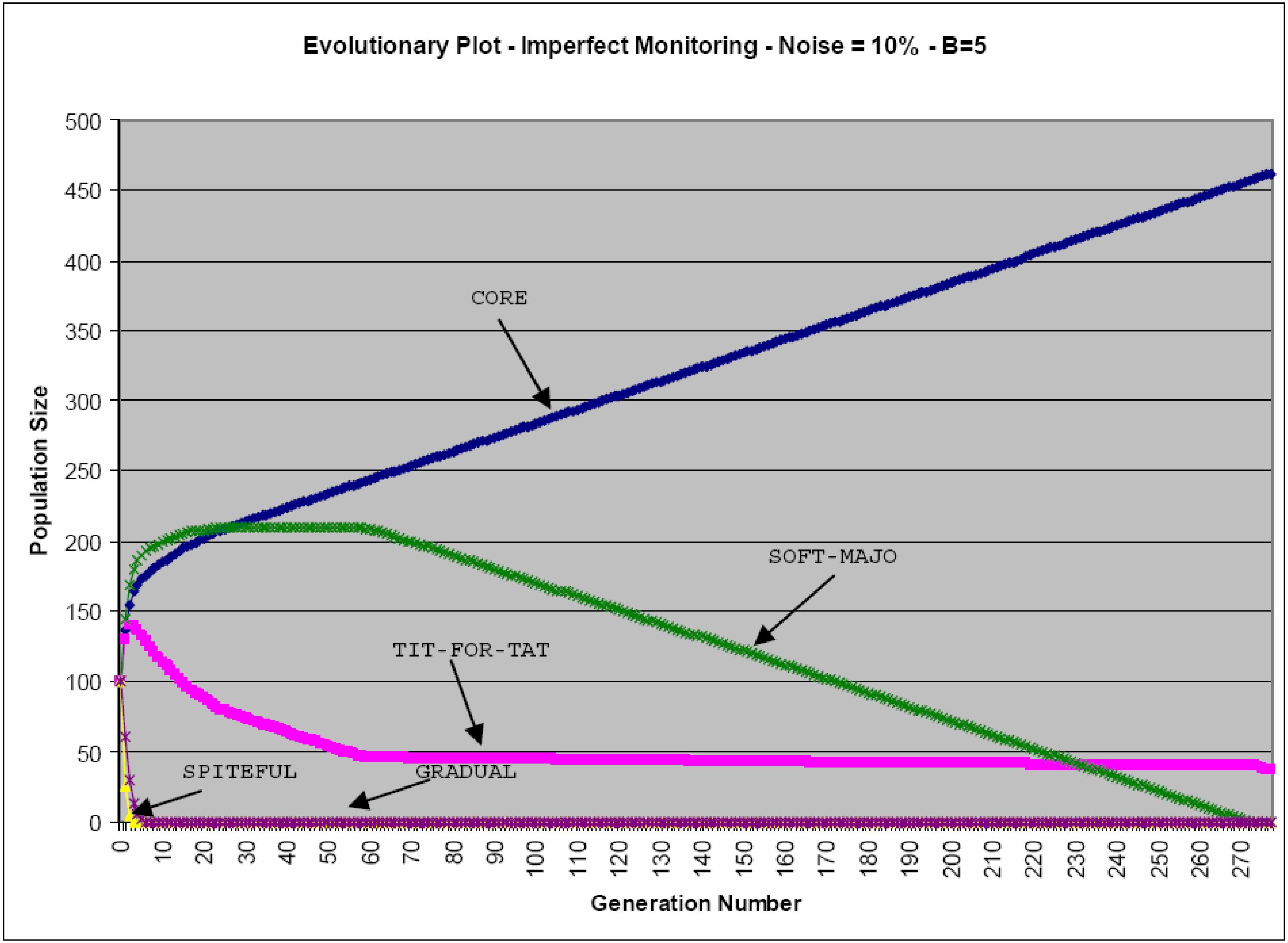

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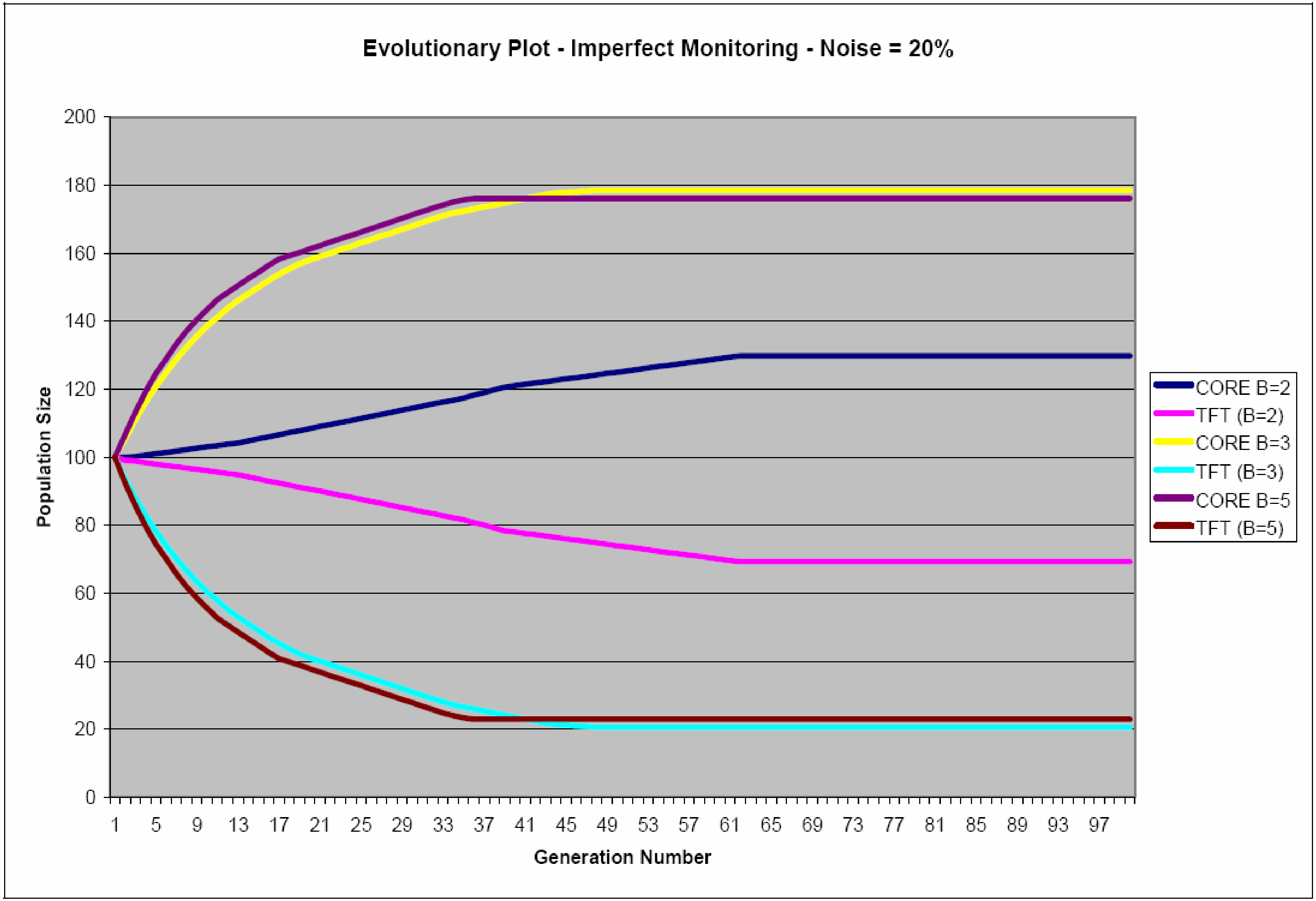

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Limitations of basic model

- Network topology is not taken into account
  - Only random pair-wise node interaction
- Coalitions and group dynamics are not considered
- Further work not presented today:
  - Cooperative game theory
    - Study the ***size*** (***k***) of a ***coalition*** of cooperating nodes
    - Nash Equilibrium → lower bound on ***k***
    - ***CORE as a Coalition Formation Algorithm***
  - Non-cooperative forwarding
    - Study the impact of network topology on equilibrium strategies

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CORE summary

- Lightweight approach
  - CORE execution consumes little energy
  - Nodes that use CORE consume less than nodes that do not use CORE
- No traffic overhead
  - No reputation distribution
- Effective in presence of misperception
- Robust against attacks
- CORE principles can be extended to higher layers
  - Service discovery
  - Overlay network formation
  - …