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USC

Framework for Modeling, Test Generation and Performance Evaluation of Wireless Ad Hoc and Sensor MAC Protocols

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Motivation

- Pressing need for a systematic approach that exposes network flaws and breaking points
- Very few protocols have been tested systematically for their performance
- Traditional performance evaluation approaches
  - Evaluate average performance
  - Do not capture extreme cases

Objective

- Provide automatic test generation framework for a broad class of protocols
  - Search based
- Traditional test generation approaches
  - Target verification
  - Uses forward search
    - Exhaustive
- Propose test generation framework
  - Adopts falsification
  - Starts from a given protocol performance objective
  - Generates conditions (Error) that adversely effect the protocol performance objective
  - Uses a mix of backward and forward searches
    - Non-exhaustive
  - Complete
    - Generates all scenarios leading to the target error

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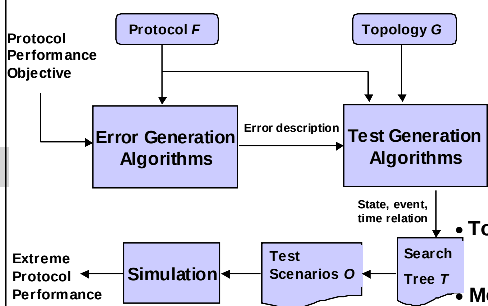
Framework



- Protocol model F
  - Finite state machine (transition table)
  - Each row defines state transition of network node for a protocol event
  - Semantics of a row in transition table
    - $<S_{in}, e_{in}, S_{out}, \{e_{out}(\text{delay } \delta)[\text{effect } \sigma]\}>$
    - At time t event e_{in} changes the state of a node from S_{in} to S_{out} and triggers event e_{out} at time $t+\delta$ effecting set of nodes σ
- Topology model G
  - G_i: neighborhood set of node i
  - G: set of G_i's for all nodes in the network
- Model of a Scenario
  - Specified in terms of network node states (H_s), protocol events (H_e), time relations as system of inequalities (SOI) between state transitions and events, and prohibited entries (PL_s, PL_e, PL_{SOI})
- Search tree T
  - A node in search tree is defined by a scenario
- Enumerating child nodes
  - An entity x is justified in tree node N if all entities sufficient to create x exist in N
  - From N, create child nodes from each unjustified entity y of N
  - Child nodes corresponds to all possible ways to justify y
  - N is a leaf node if all entities are justified
- Search space reduction using implication
  - Create node state and event history from current states, events and time relations
  - Check consistency of child nodes and eliminate inconsistent child nodes earlier

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Case Study: IEEE 802.11

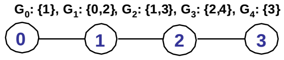
Part of Transition Table F

	Start State	Input event	End State	Output event
1	$Idle_i$	$Pkt_{i,j}$	Tx_i	$RTS_{i,j}$-TS(0)[i], $RTS_{i,j}$-RS(d)[G_i], $RTS_{i,j}$-TE(α_r)[i], $RTS_{i,j}$-RE(d+α_r)[G_i]
2	Tx_i	$RTS_{i,j}$-TE	$WCTS_i$	$CTST_i$-S(0)[i], $CTST_i$-E(d+Δ+α_r)[I]
3	$WCTS_i$	$CTS_{i,j}$-RS	$WCTSAR_i$	
4	$WCTSAR_i$	$CTS_{i,j}$-RE	WSIFS-C_i	$SIFST_i$-S(0)[i], $SIFST_i$-E(Δ)[I]
5	WSIFS-C_i	SIFST-E_i	Tx_i	$Data_{i,j}$-TS(0)[i], $Data_{i,j}$-RS(d)[G_i], $Data_{i,j}$-TE(β)[i], $Data_{i,j}$-RE(d+ β)[G_i]

Notations:
States: Tx (transmitting), WCTS (wait-for-CTS), WCTSAR (WCTS and receiving)
Event: Pkt (packet at node i for node j), RTS-TS(RTS-transmit-start), RTS-RS(RTS-receive-start), RTS-TE(RTS-transmit-end), RTS-RE(RTS-receive-end), SIFST-S (SIFS timer start), SIFST-E (SIFS timer end)
Time variables: α_r (RTS transmission/reception), d (propagation delay), β (Data transmission), Δ (SIFS interval)
Transition 1: $Pkt_{i,j}$ event at time t at node i, changes its state from Idle to Tx and triggers following events: 1) RTS-TS at time t, affects node i 2) RTS-RS at $t+d$, affects nodes in G_i 3) RTS-TE at $t+\alpha_r$, affects node i and 4) RTS-RE at $t+d+\alpha_r$, affects nodes in G_i

Topology Model G

G_0: {1}, G_1: {0,2}, G_2: {1,3}, G_3: {2,4}, G_4: {3}



Error Description

- Collision
  - Two messages m_1 and m_2 collide at a node i if their reception has an overlapping interval at i
  - Error E: collision at node 1
    - States: 1: <BOCOL τ_0, t_1>
    - Time relations
      1. $\tau_0 < t_1 + \beta$

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Error Generation: Algorithms and Result

- Performance objective: Throughput
  - α is the amount of data successfully transmitted in time β
  - Throughput = α / β
- Our study objective: to minimize throughput
- Target events that penalize our study objective
  - Data-RE (successful data reception), ACK-RE
- Conditions (Error descriptions) to meet the target events
  - BOCOL (Backoff due to collision)
  - BOFT (Backoff on failed transmission)
  - Defer (Drops packet silently one defer)

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Test Scenario Generation: Collision

T_n:
H_e: $Data_{0,1}$-RS@t_0, $Data_{0,1}$-RE@t_1, $Data_{2,3}$-RS@τ_0, $Data_{0,1}$-RE@τ_1
SOI: (1) $t_1=t_0+\beta$
(2) $\tau_1=\tau_0+\beta$
(3) ($t_0\le\tau_0$, $\tau_0<t_1$) or ($\tau_0\le t_0$, $t_0<\tau_1$)

Implication: Reception ← Transmission

T_n:
H_e: $Data_{0,1}$-RS@t_0, $Data_{0,1}$-RE@t_1, $Data_{2,3}$-RS@τ_0, $Data_{0,1}$-RE@τ_1, $Data_{0,1}$-TS@t_2, $Data_{2,3}$-TS@τ_2
SOI: (1) $t_1=t_0+\beta$
(2) $\tau_1=\tau_0+\beta$
(3) ($t_0\le\tau_0$, $\tau_0<t_1$) or ($\tau_0\le t_0$, $t_0<\tau_1$)
(4) $t_2=t_0$-d
(5) $\tau_2=\tau_0$-d

T_{n+1}:

H_e: $Data_{0,1}$-RS@t_0, $Data_{0,1}$-RE@t_1, $Data_{2,3}$-RS@τ_0, $Data_{0,1}$-RE@τ_1, $Data_{0,1}$-TS@t_2, $Data_{2,3}$-TS@ τ_2, SIFST-E_0@t_2, SIFST-E_2@ τ_2
H_s: 0:<WSIFS-C, _, t_2>, 0:<Tx, t_2,_>, 2:<WSIFS-C, _, τ_2>, 2:<Tx, τ_2,_>
SOI: (1) $t_1=t_0+\beta$
(2) $\tau_1=\tau_0+\beta$
(3) $t_2=t_0$-d
(4) $\tau_2=\tau_0$-d
(5) $t_0\le\tau_0$
(6) $\tau_0<t_1$

H_e: $Data_{0,1}$-RS@t_0, $Data_{0,1}$-RE@t_1, $Data_{2,3}$-RS@τ_0, $Data_{0,1}$-RE@τ_1, $Data_{0,1}$-TS@t_2, $Data_{2,3}$-TS@ τ_2, SIFST-E_0@t_2, SIFST-E_2@ τ_2
H_s: 0:<WSIFS-C, _, t_2>, 0:<Tx, t_2,_>, 2:<WSIFS-C, _, τ_2>, 2:<Tx, τ_2,_>
SOI: (1) $t_1=t_0+\beta$
(2) $\tau_1=\tau_0+\beta$
(3) $t_2=t_0$-d
(4) $\tau_2=\tau_0$-d
(5) $\tau_0\le t_0$
(6) $t_0<\tau_1$

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Underlined entities are unjustified in tree node

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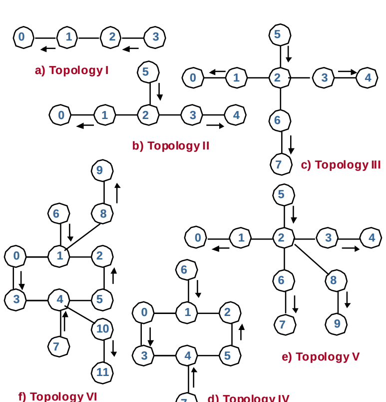
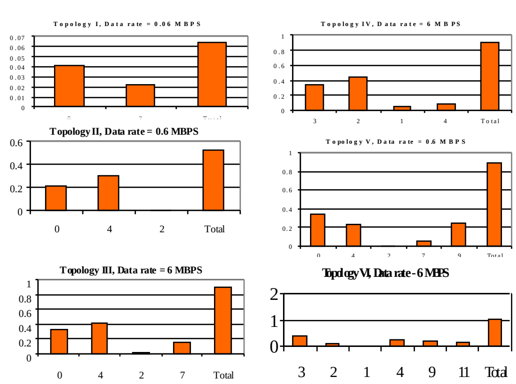
Simulation Results

- ns-2 simulations of generated test scenarios
- Starting from basic topology (topology I), construct topologies systematically to
  - allow more nodes to starve (throughput)
  - allow a target node to starve more (fairness)

Simulated Topologies



X axis: Node ID, Y Axis: Throughput in MBPS



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Conclusions & Future Work

- A test generation framework for performance evaluation of wireless MAC protocols
  - Complexity of search is reduced by using mix of forward and backward search, and implication
- Generated scenarios expose extreme performance of the protocol under study
  - Average network throughput of some scenarios are 3%
  - Average network throughput of random scenario 45-65%
- Work in progress: analyze worst case performance

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