Cognitive Radio Simulations in NS2

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Goals

- To study of the effect of scanning duration on the Cognitive Radio network throughput in a WLAN primary through NS2 simulations.

- Analytical models for WLAN networks already exist in literature
- We extend one such model to include the effects of scanning delay, sensing errors on the throughput performance of CR
- Bianchi's discrete time Markov Chain model for WLAN Networks is a popular and accurate analytical model
- However, Bianchi's model is for a saturated network. We extend this to model unsaturated networks

DCF

- In WLAN, the fundamental mechanism to access the medium is called Distributed Coordination Function (DCF)
- DCF is a random access scheme, based on the Carrier Sense Multiple Access scheme with Collision Avoidance (CSMA/CA)

Random Backoff of DCF

When there is a packet to be transmitted and if the channel is found to be free, then:

- DCF chooses a backoff time uniformly distributed in the range [0,W-1], where W is called the Contention Window length
- At the first transmission attempt, W is set to W_0
- After each unsuccessful attempt, W is doubled, going up to a maximum value of $W_m = 2^m W_0$
- After the successful transmission, W is reset back to W_0
- Once a back-off time is chosen, the back-off timer is decremented each time the channel is sensed free, else it is paused until the channel is sensed free again

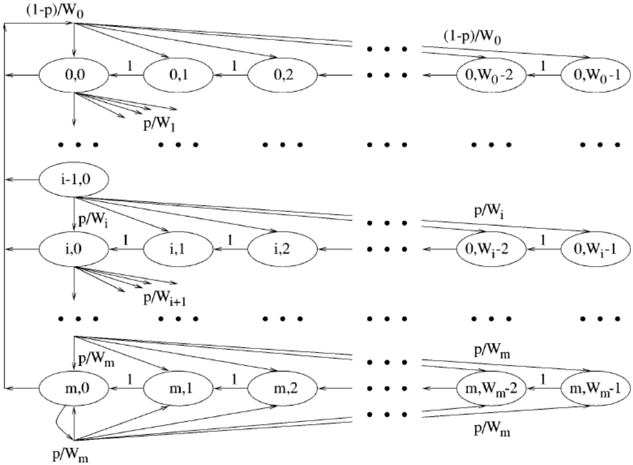


Figure: Source: G. Bianchi, "Performance analysis of IEEE 802.11 distributed Coordination function", IEEE Journal on Selected Areas in Communications, Vol. 18, No. 3, pp. 535-547, March 2000

Assumptions

- The main goal of the analysis is to obtain the stationary probability τ that a particular transmitter transmits in any randomly chosen slot time. The rest of the parameters (throughput, delay) follow from τ
- The key approximation in the analysis is that, at each transmission attempt, regardless of the number of transmission attempts, the transmission suffers a constant and independent probability p
- All the nodes are assumed to be in saturation, which means a node will always have a packet to transmit

Evaluation of τ

- From the definition of τ:

$$\tau = \sum_{i=0}^{m} b_{i,0}$$

- After finding the stationary distribution of the Markov Chain:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1) + pW(1-(2p)^m)}$$

- The probability p with which a transmitted packet encounters a collision is the probability that at least one of the other nodes also transmit in the given slot

$$p = 1 - (1-\tau)^{n-1}$$

Throughput

- The throughput (R) of the network is defined as the fraction of the time the channel is used to successfully transmit the packet

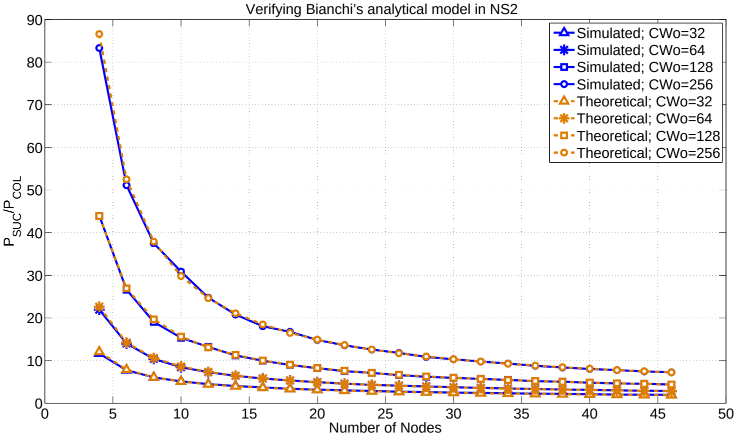
$$R = \frac{E[\text{Amount of time spent in successful transmission}]}{E[\text{Length of a slot time}]}$$

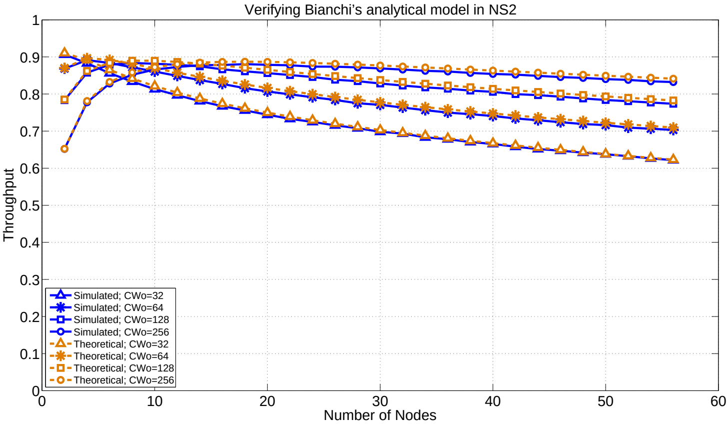
$$R = \frac{P_{suc} T_{suc}}{P_{idle} T_{idle} + P_{col} T_{col} + P_{suc} T_{suc}}$$

$$P_{idle} = (1-\tau)^n$$

$$P_{suc} = n\tau(1-\tau)^{n-1}$$

$$P_{col} = 1 - n\tau(1-\tau)^{n-1} - (1-\tau)^n$$


Verifying Bianchi's analytical model in NS2
P_{SUC}/P_{COL}
Number of Nodes
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40
45
50
Simulated; CWo=32
Simulated; CWo=64
Simulated; CWo=128
Simulated; CWo=256
Theoretical; CWo=32
Theoretical; CWo=64
Theoretical; CWo=128
Theoretical; CWo=256


Verifying Bianchi's analytical model in NS2
Throughput
Number of Nodes
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
Simulated; CWo=32
Simulated; CWo=64
Simulated; CWo=128
Simulated; CWo=256
Theoretical; CWo=32
Theoretical; CWo=64
Theoretical; CWo=128
Theoretical; CWo=256

Cognitive Radio Setup

- The CR nodes are required to scan the spectrum periodically for the availability of the channel
- All the CR nodes perform the scan procedure simultaneously
- The scan procedure is performed with a period T, each scan procedure lasts for a time t
- The CR network has $T - t$ useful time for its transmission, upon the availability of the channel
- All the nodes in the network (both primary & secondary) are assumed to be in saturation

MAC Layer issues

- The packet transmission is said to be complete if RTS/CTS and Packet/ACK are successfully exchanged between communicating nodes
- In the Cognitive Radio Network, if the remaining useful time is not sufficient for the complete transmission, we follow certain rules:
    - If the remaining useful time is not sufficient even for RTS transmission, discard the packet. The opportunity to transmit is lost and the node has to contend for the channel again
    - If RTS can fit, but not CTS, the node transmits RTS. Upon the next availability of the channel, the intended receiver has to transmit CTS after a delay of SIFS from the finish of the scan procedure

Contd...

- If both RTS and CTS can fit, but not the data packet, resume data transmission after SIFS from scan procedure, again upon the next availability of the channel
- If RTS/CTS and the data packet can fit, but not the ACK, the receiver transmits ACK after SIFS upon the next availability of the channel
- All the remaining nodes have to pause their backoff procedure until a duration DIFS from the end of the scan procedure and upon the availability of the channel

Evaluation of the Cognitive Radio network parameters

- The network can be in one of two possible states:
  - State-1: Secondary nodes have frozen their transmission; only primary nodes are active
  - State-2: All the nodes in the network are active; secondary nodes are also active as the result of the previous scan is *free*
    - In this case, all nodes (primary + secondary) contend for the channel till the next scan procedure
- Therefore, the network has two sets of transmission parameters, one for each state

State-1

- The network has only primary nodes being active. Hence, the transmission ($\tau_{p,1}$) and the collision ($p_{p,1}$) probabilities are given by:

$$\tau_{p,1} = \frac{2(1-2p_{p,1})}{(1-2p_{p,1})(1+W_p) + p_{p,1}W_p(1-(2p_{p,1})^{M_p})}$$

$$p_{p,1} = 1 - (1-\tau_{p,1})^{N_p - 1}$$

- N_p is the number of primary nodes, M_p is the number of back-off stages of each primary node, W_p is the initial contention window length of each primary node
- As the secondary nodes are inactive in this state, their transmission probability is zero

State-2

- In this state transmission and collision probabilities are given by:

$$\tau_{p,2} = \frac{2(1-2p_{p,2})}{(1-2p_{p,2})(1+W_p)+p_{p,2}W_p(1-(2p_{p,2})^{M_p})}$$

$$\tau_{s,2} = \frac{2(1-2p_{s,2})}{(1-2p_{s,2})(1+W_s)+p_{s,2}W_s(1-(2p_{s,2})^{M_s})}$$

$$p_{p,2} = 1-(1-\tau_{p,2})^{N_p-1}(1-\tau_{s,2})^{N_s}$$

$$p_{s,2} = 1-(1-\tau_{p,2})^{N_p}(1-\tau_{s,2})^{N_s-1}$$

- N_s is the number of secondary nodes, M_s is the number of back-off stages of each secondary node, W_s is the initial contention window length of each secondary node

Definition of α_c, α_{busy}, α_{idle}

- $\alpha_c \triangleq$ probability with which the network is in State-1
- $\alpha_{busy} \triangleq$ probability with which the network will be in State-1 given that the previous state of network is State-1
- $\alpha_{idle} \triangleq$ probability with which the network will be in State-1 given that the previous state of network is State-2
- α_c can be recursively written as:

$$\alpha_c = \alpha_c \alpha_{busy} + (1 - \alpha_c)\,\alpha_{idle}$$

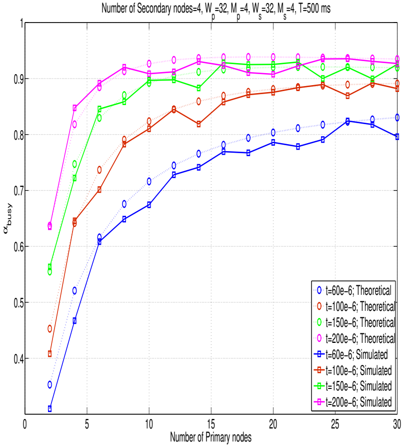
$$\Rightarrow \alpha_c = \frac{\alpha_{idle}}{1 + \alpha_{idle} - \alpha_{busy}}$$

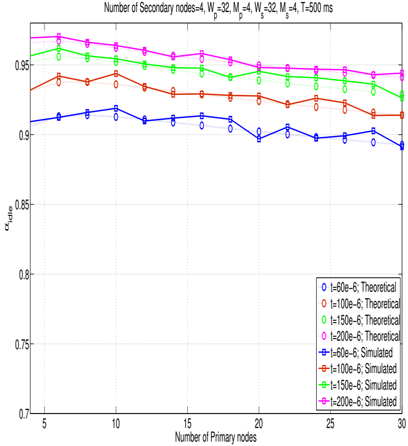
Importance of α_c

- The availability of the channel for the secondary network is determined by the parameter α_c
- α_c reflects the effect of sensing duration and sensing errors, which therefore makes it an important network parameter

Simulations

α_{busy} and α_{idle}:





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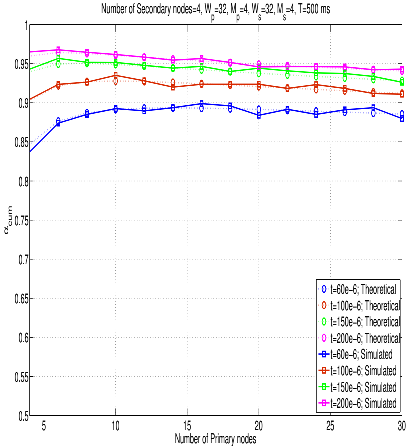
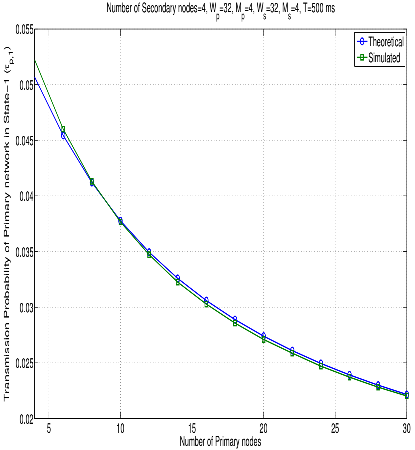
α_c and $\tau_{p,1}$





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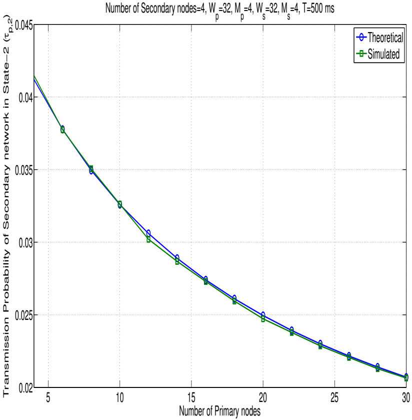
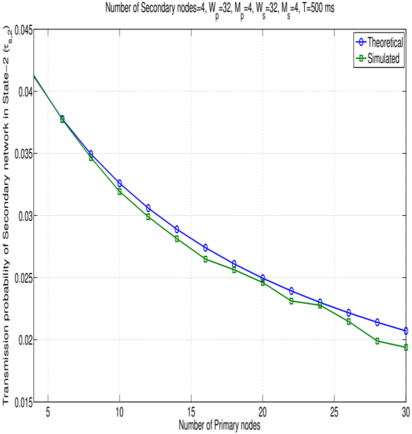
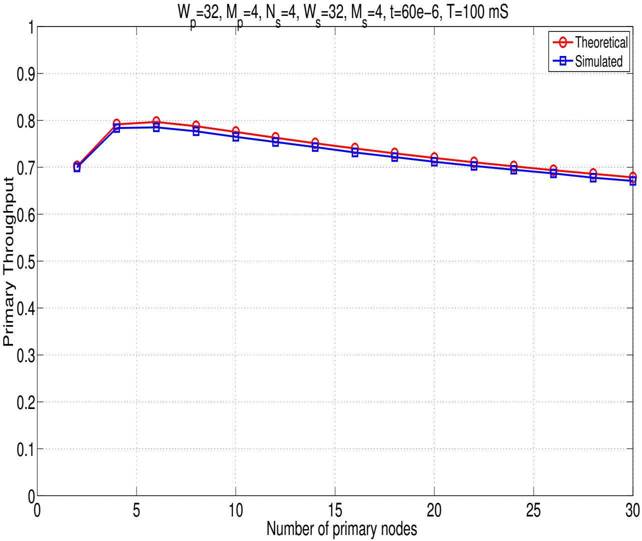
$\tau_{p,2}$ and $\tau_{s,2}$

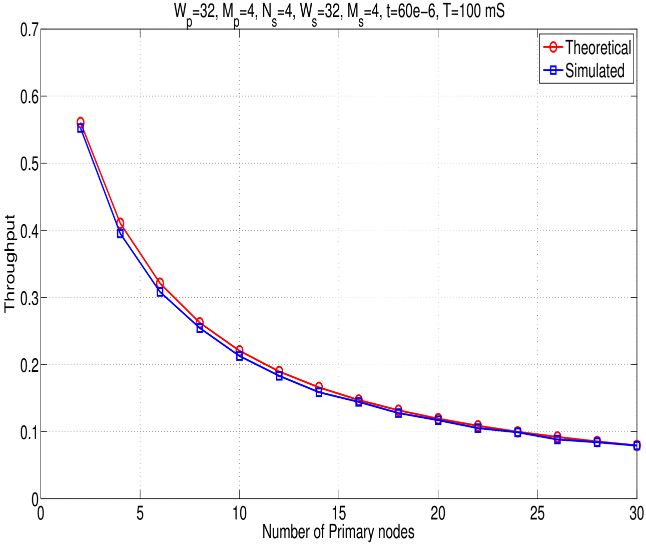




Comparison of Theoretical and Simulated Throughput

- The plots below show the simulated and theoretical achievable throughputs for both the primary and secondary network
- The primary throughput is the fraction of the time spent in transmitting packets successfully, averaged over different states of the network
- As the secondary network is not active in the State-1, its throughput is calculated as the fraction of the time spent in transmitting packets successfully in the useful time $T - t$, when the channel is available


W_p=32, M_p=4, N_s=4, W_s=32, M_s=4, t=60e−6, T=100 mS
Theoretical
Simulated
Primary Throughput
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
25
30
Number of primary nodes


W_p=32, M_p=4, N_s=4, W_s=32, M_s=4, t=60e−6, T=100 mS
Theoretical
Simulated
Throughput
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
5
10
15
20
25
30
Number of Primary nodes

- In the previous section, analysis was done for saturated networks. However it is of practical interest to extend the study to unsaturated networks (particularly when the primary is unsaturated)
- As a first step, a network of only WLAN nodes (the nodes are unsaturated) is modeled with a modified Bianch's Markov model and its compared performance with the simulations.
- The future work includes extending this model to include non-saturated cognitive nodes and study the throughput performance

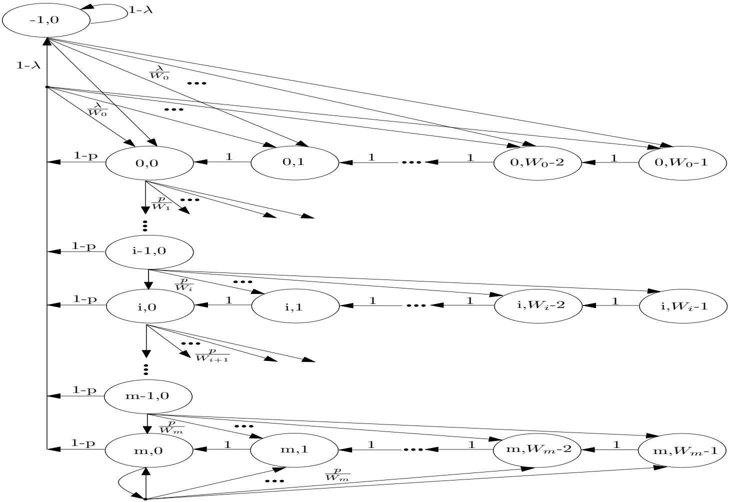


Figure: Modified Markov model. The parameter λ quantifies the saturation of the network. The greater the λ, the busier the network.

Transmission Parameters

- The transmission (τ) and the collision probability (p) for the above unsaturated model is given by:

$$\tau = \frac{2(1-2p)}{(1-2p)(CW_o+1)+pCW_o(1-(2p)^M)+2(1-2p)(1-p)\frac{1-\lambda}{\lambda}}$$

$$p = 1-(1-\tau)^{n-1}$$

- CW_o is the initial contention window length, M is the number of back-off stages and N is the number of nodes in the network

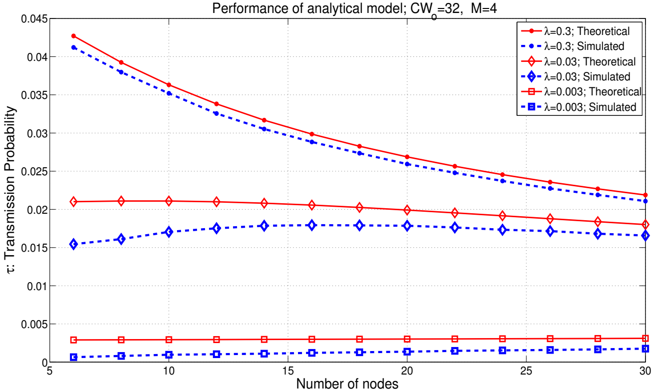


Figure: For smaller λ, due to an approximation made in the Markov model (which itself came from Bianchi's Markov model), the theoretical predictions are accurate only for a large number of nodes ($\approx$ 100 nodes). However, even in other regimes, the performance is satisfactory.

Thank You

Questions?