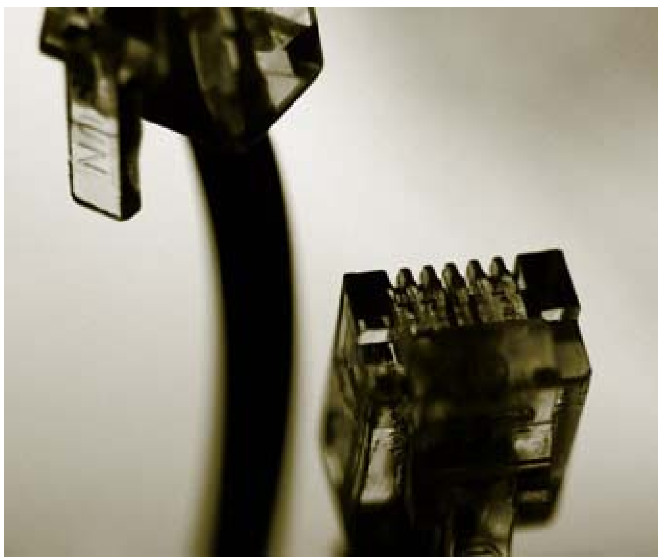
802.11 Wireless Network Extended Service Set Model



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Outline

- **Introduction**
- ESS model
- System characteristics
- Conclusions
- Future work

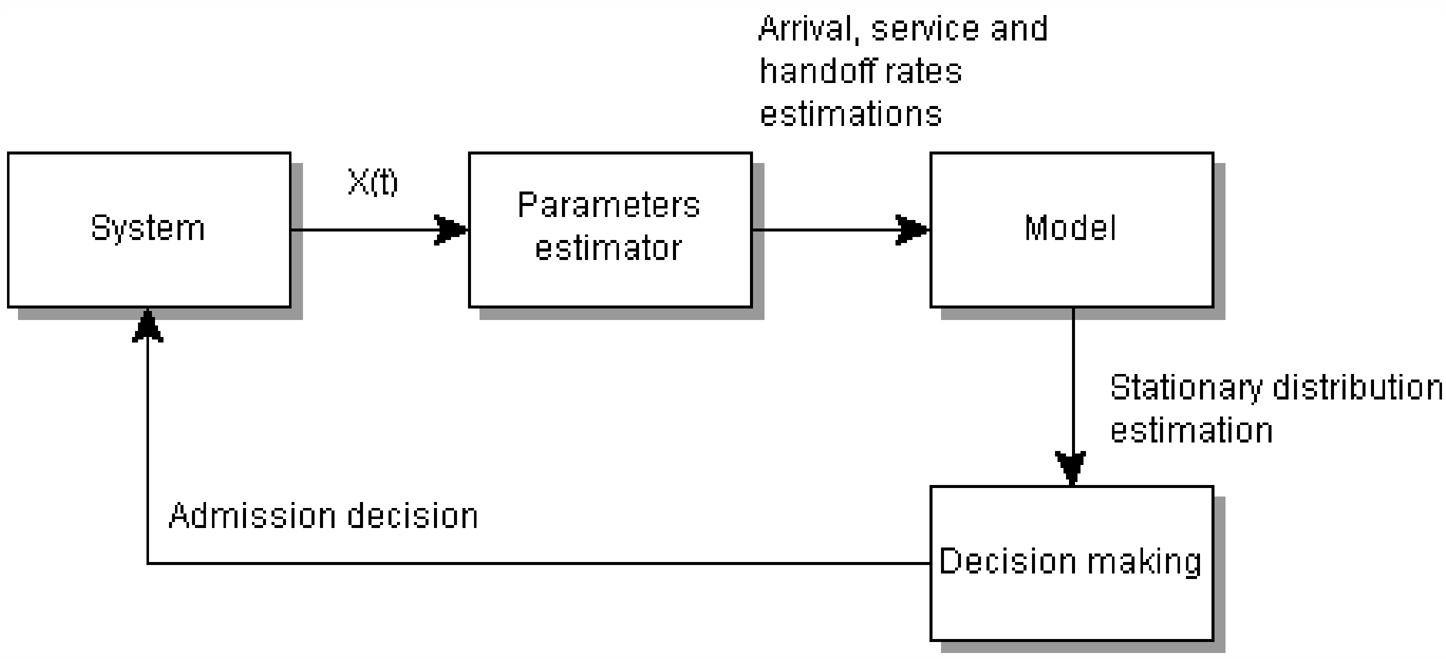
Introduction

- Limited radio spectrum allocated to wireless communications & increasing population of wireless users
- A wireless STA can join BSS, leave ESS and move from one BSS to another within a given ESS (handoff)
- For an user an initial refusal of service is more acceptable then a sudden lost of service as a result of handoff blocking due to mobility
- 802.11 standard imposes a restriction on the number of STAs an AP point may serve

Introduction (Cont)

- Admission control is required to minimize handoff blocking probability and fully utilize available bandwidth
- For a given BSS we have to take into account and constantly monitor combined state of all neighbor BSSs within an ESS
- A distributed admission control algorithm can make a decision whether to accept or deny a new connection request in order to minimize handoff blocking probability

Introduction (Cont)



Adaptive admission control

Introduction (Cont)

- A mathematical model of an ESS as a queuing system is required to efficiently perform admission control
- Blocking probabilities could be calculated without observing the actual blocking and corresponding admission decision would be made
- Recalculation after every system's state change (new admission, departure or handoff) would be necessary for neighbor APs

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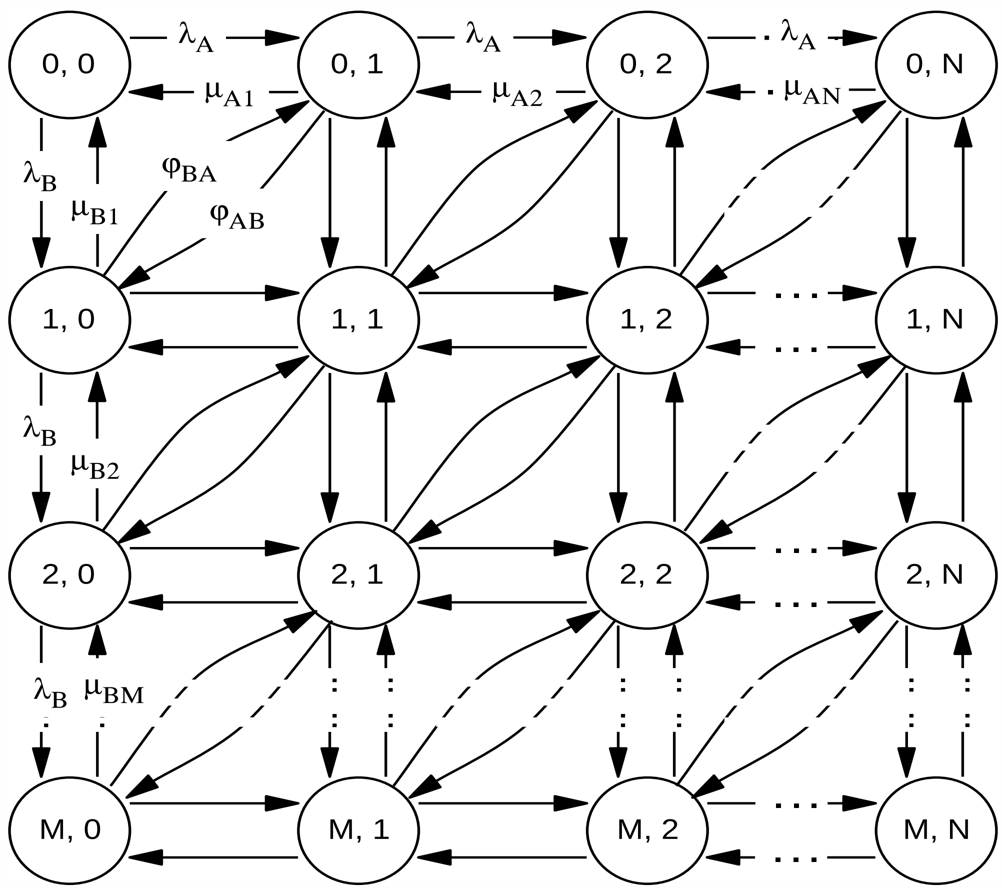
ESS model

- Consider a simple ESS with two BSSs: BSS_A and BSS_B
- Such a system can be represented as continuous time quasi-birth-and-death (QBD) Markov process
- The state *(i; j)* represents the number of associated wireless stations in BSS_A and BSS_B respectively

ESS model (Cont)



Markov chain for the ESS model

- λ_A and λ_B are new stations arrival rates for BSS_A and BSS_B
- μ_{Ai} and μ_{Bi} are service rates of BSS_A and BSS_B with i associated stations
- $N + 1$ and $M + 1$ are maximum number of wireless stations that can be served by BSS_A and BSS_B respectively
- φ_{AB} and φ_{BA} are handoff rates

ESS model (Cont)

An example of corresponding infinitesimal generator *Q*, *M*=*N*=2

$$
Q = \begin{array}{c} \\ (0,0) \\ (0,1) \\ (0,2) \\ (1,0) \\ (1,1) \\ (1,2) \\ (2,0) \\ (2,1) \\ (2,2) \end{array}
\begin{array}{c}
\begin{array}{ccccccccc} (0,0) & (0,1) & (0,2) & (1,0) & (1,1) & (1,2) & (2,0) & (2,1) & (2,2) \end{array} \\
\left(\begin{array}{ccc|ccc|ccc}
s_{00} & \lambda_A & 0 & \lambda_B & 0 & 0 & 0 & 0 & 0 \\
\mu_{A1} & s_{01} & \lambda_A & \varphi_{AB} & \lambda_B & 0 & 0 & 0 & 0 \\
0 & \mu_{A2} & s_{02} & 0 & \varphi_{AB} & \lambda_B & 0 & 0 & 0 \\
\hline
\mu_{B1} & \varphi_{BA} & 0 & s_{10} & \lambda_A & 0 & \lambda_B & 0 & 0 \\
0 & \mu_{B1} & \varphi_{BA} & \mu_{A1} & s_{11} & \lambda_A & \varphi_{AB} & \lambda_B & 0 \\
0 & 0 & \mu_{B1} & 0 & \mu_{A2} & s_{12} & 0 & \varphi_{AB} & \lambda_B \\
\hline
0 & 0 & 0 & \mu_{B2} & \varphi_{BA} & 0 & s_{20} & \lambda_A & 0 \\
0 & 0 & 0 & 0 & \mu_{B2} & \varphi_{BA} & \mu_{A1} & s_{21} & \lambda_A \\
0 & 0 & 0 & 0 & 0 & \mu_{B2} & 0 & \mu_{A2} & s_{22}
\end{array}\right)
\end{array}
$$

ESS model (Cont)

$$Q = \begin{pmatrix} A_1^{(0)} & A_0 & 0 & \cdots & 0 & 0 & 0 \\ A_2^{(1)} & A_1^{(1)} & A_0 & \cdots & 0 & 0 & 0 \\ 0 & A_2^{(2)} & A_1^{(2)} & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & A_2^{(i)} & A_1^{(i)} & A_0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & A_2^{(M-1)} & A_1^{(M-1)} & A_0 \\ 0 & 0 & 0 & 0 & 0 & A_2^{(M)} & A_1^{(M)} \end{pmatrix}$$

Where square matrices A_0, $A^{(i)}{}_1$ and $A^{(i)}{}_2$ are of order $N + 1$ are defined as follows:

$$A_0 = \begin{pmatrix} \lambda_B & 0 & 0 & 0 & \cdots & 0 \\ \varphi_{AB} & \lambda_B & 0 & 0 & \cdots & 0 \\ 0 & \varphi_{AB} & \lambda_B & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \varphi_{AB} & \lambda_B & 0 \\ 0 & 0 & 0 & 0 & \varphi_{AB} & \lambda_B \end{pmatrix}$$

$$A_1^{(i)} = \begin{pmatrix} s_{i0} & \lambda_A & 0 & 0 & \cdots & 0 \\ \mu_{A1} & s_{i1} & \lambda_A & 0 & \cdots & 0 \\ 0 & \mu_{A2} & s_{i2} & \lambda_A & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \mu_{AN-1} & s_{iN-1} & \lambda_A \\ 0 & 0 & 0 & 0 & \mu_{AN} & s_{iN} \end{pmatrix}$$

$$A_2^{(i)} = \begin{pmatrix} \mu_{Bi} & \varphi_{BA} & 0 & 0 & \cdots & 0 \\ 0 & \mu_{Bi} & \varphi_{BA} & 0 & \cdots & 0 \\ 0 & 0 & \mu_{Bi} & \varphi_{BA} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \mu_{Bi} & \varphi_{BA} \\ 0 & 0 & 0 & 0 & 0 & \mu_{Bi} \end{pmatrix}$$

ESS model (Cont)

- Matrix analytic methods exploit the special structure of the infinitesimal generator *Q*
- Linear level reduction (LLR) and reverse LLR methods were used to obtain stationary distribution vector $\pi = (\pi_0, \pi_1, \cdots, \pi_M)$:

$$\pi_0 = \pi_0 U^{(0)},$$

$$\pi_i = \pi_{i-1} R^{(i)}, \quad for \ 1 \leq i \leq M$$

$$\sum_{0 \leq i \leq M} \pi_i \zeta = 1$$

ESS model (Cont)

where

$$
\begin{aligned}
R^{(i)} &= A_0(-U^{(i)})^{-1}, \quad 1 \le i \le M \\
U^{(M)} &= A_1^{(M)}, \\
U^{(i)} &= A_1^{(i)} + A_0(-U^{(i+1)})^{-1}A_2^{(i+1)}, \quad 1 \le i \le M-1 \\
U^{(0)} &= A_1^{(0)} + A_0(-U^{(1)})^{-1}A_2^{(1)}.
\end{aligned}
$$

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System characteristics

- Blocking probabilities of the BSSs and the system
- Handoff blocking probabilities
- Relative throughput of the BSSs and the system
- Absolute throughput of the BSSs and the system
- Average number of wireless stations in BSS_A, BSS_B and the ESS
- Average time a station spends in the system

System characteristics (Cont)

Blocking probability for BSS_A: $$P_{Bl}^{A} = \sum_{i=0}^{M} \rho_{iN}$$

Blocking probability for BSS_B: $$P_{Bl}^{B} = \sum_{j=0}^{N} \rho_{Mj}$$

Total blocking probability: $$P_{Bl} = P_{Bl}^{A} + P_{Bl}^{B} - \rho_{MN}$$

System characteristics (Cont)

Handoff blocking probabilities:

$$P_{HBl}^{AB} = \sum_{j=0}^{N} \rho_{Mj} - \rho_{M0}, \quad and$$

$$P_{HBl}^{BA} = \sum_{i=0}^{M} \rho_{iN} - \rho_{0N}$$

System characteristics (Cont)

Relative throughput is a ratio of the average number of admitted stations to the average number of all stations trying to join a wireless network per unit time:

$$q_A = 1 - P_{Bl}^{A}, \quad and$$
$$q_B = 1 - P_{Bl}^{B}$$

a probability that a new station will be admitted

System characteristics (Cont)

Absolute throughput could be represented as the average number of stations admitted per unit time:

$$
\begin{aligned}
A_A &= \lambda_A q_A + \varphi_{BA}(1 - P_{HBl}^{BA}), \quad and \\
A_B &= \lambda_B q_B + \varphi_{AB}(1 - P_{HBl}^{AB})
\end{aligned}
$$

The average number of wireless stations:

$$
\begin{aligned}
\bar{N}_A &= E\{N_A\} = \sum_{j=0}^{N} \sum_{i=0}^{M} j \rho_{ji}, \quad and \\
\bar{N}_B &= E\{N_B\} = \sum_{i=0}^{M} \sum_{j=0}^{N} i \rho_{ij}
\end{aligned}
$$

System characteristics (Cont)

- The system characteristics were calculated using the following parameters:

$$\lambda_A = 10$$

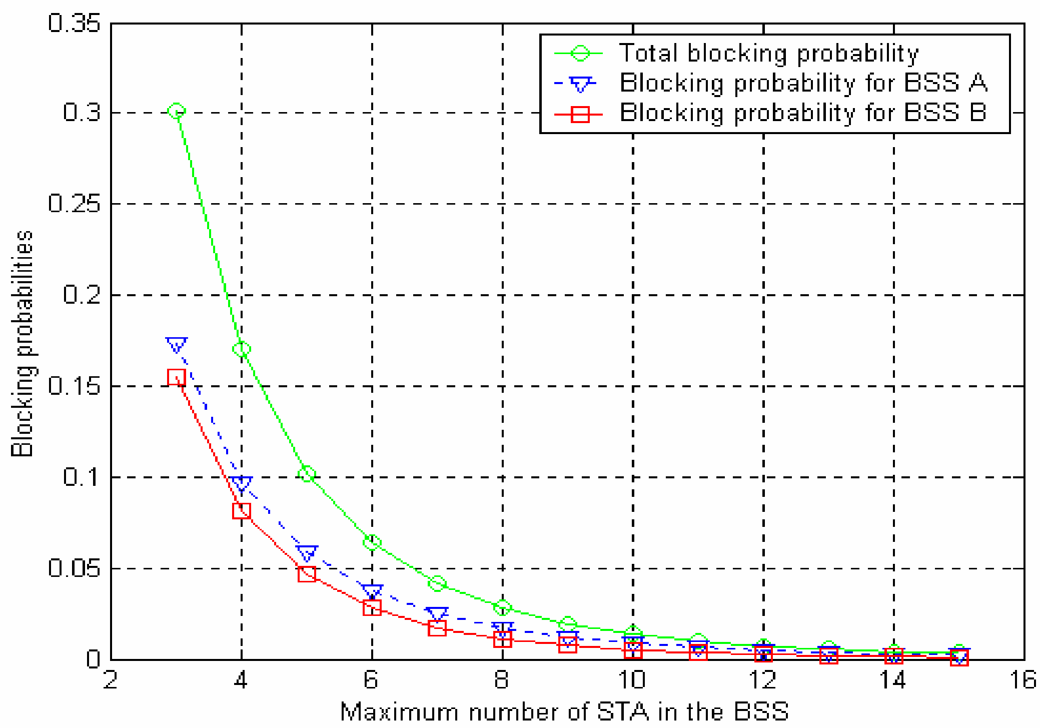
$$\lambda_B = 9$$

$$\mu_{A0} = \mu_{B0} = 20$$

$$\varphi_{AB} = \varphi_{BA} = 3$$

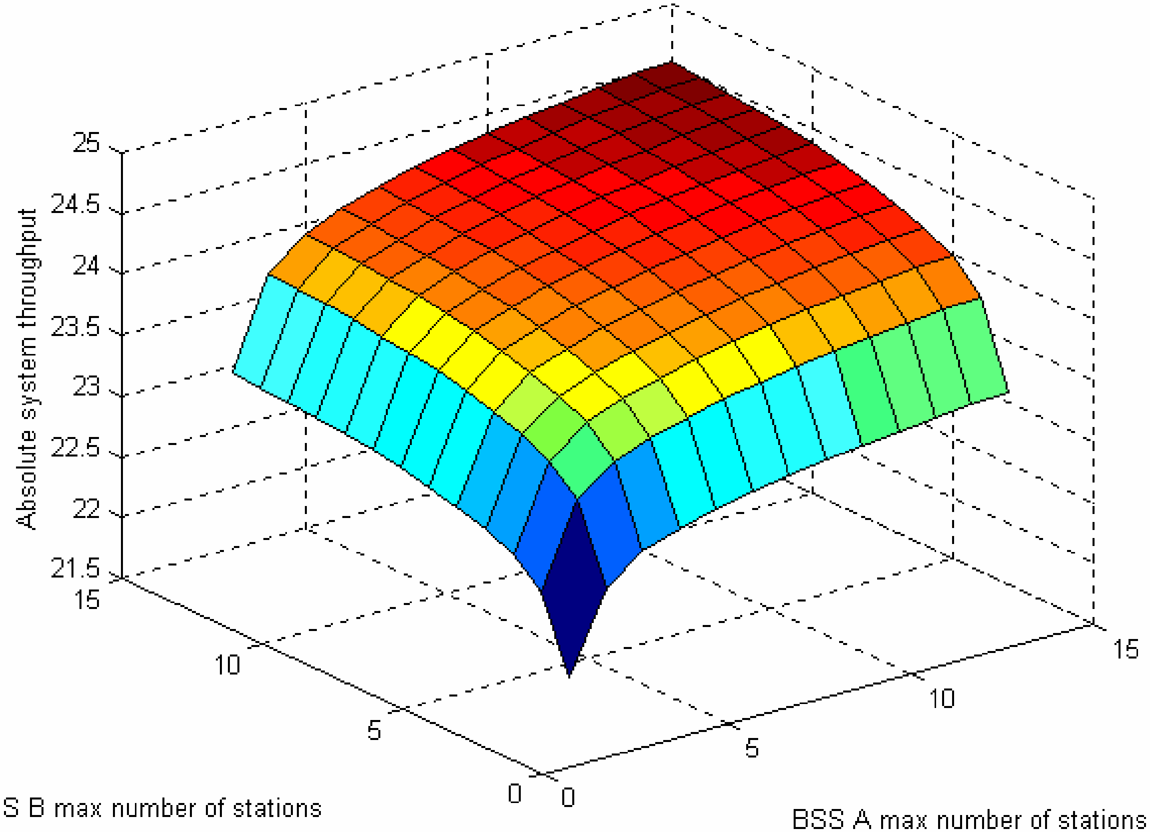
- Maximum number of wireless stations for both BSSs was set to $M = N = 15$

System characteristics (Cont)



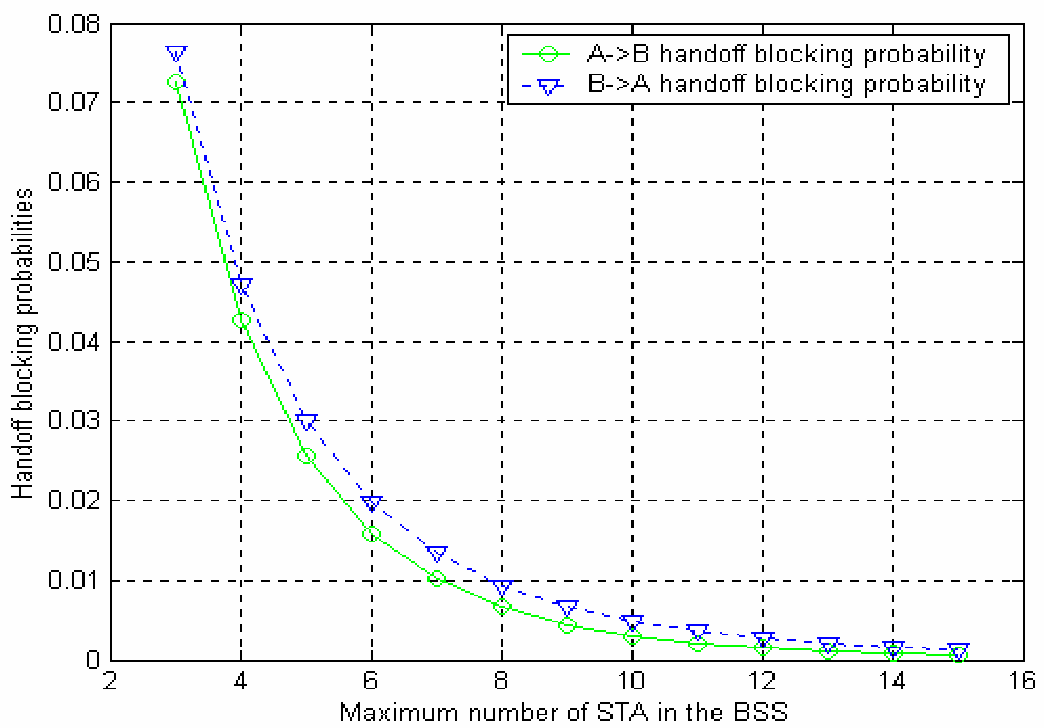
Blocking probabilities vs. maximum number of wireless stations in a BSS

System characteristics (Cont)



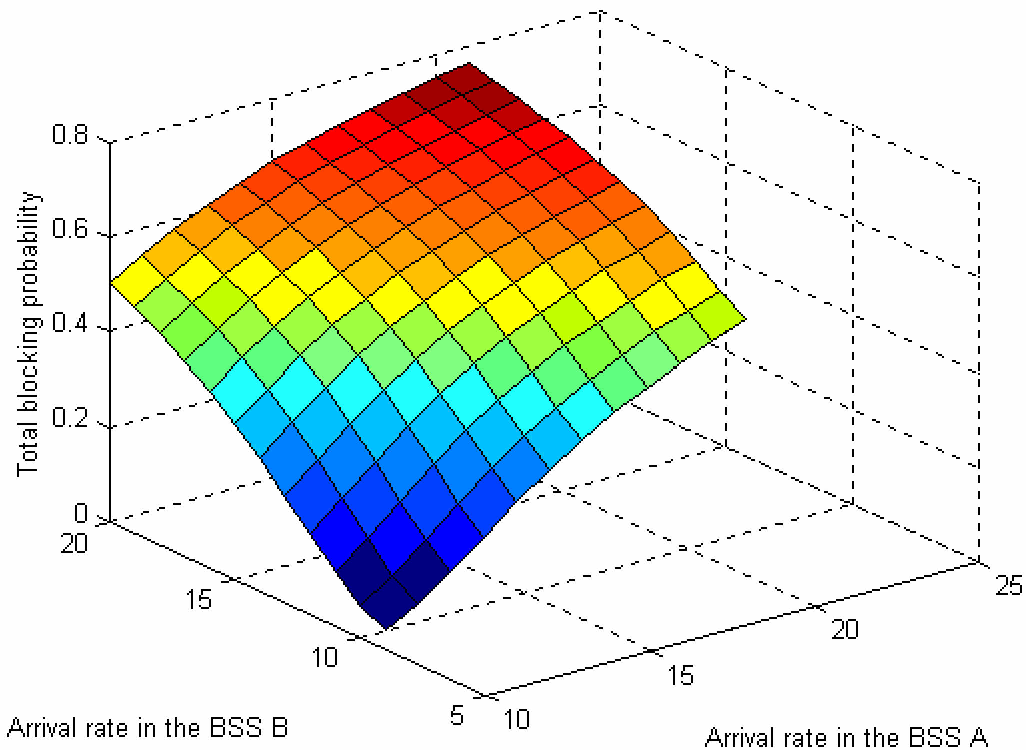
Absolute system throughput vs. maximum number of wireless stations for BSS_A and BSS_B

System characteristics (Cont)



Handoff blocking probabilities vs. maximum number of wireless stations in a BSS

System characteristics (Cont)



Total blocking probability vs. new stations arrival rate for BSS_A and BSS_B

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Conclusions

- The mathematical model of the 802.11 Extended Service Set necessary to efficiently perform admission control in a real time is developed
- Essential system characteristics are obtained based on the system stationary distribution

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Future work

- Model extension to a multiple number of infrastructure BSSs
- Estimations of arrival, handoff and service rates
- Designing distributed admission control algorithm, which minimizes handoff dropping probability

Questions