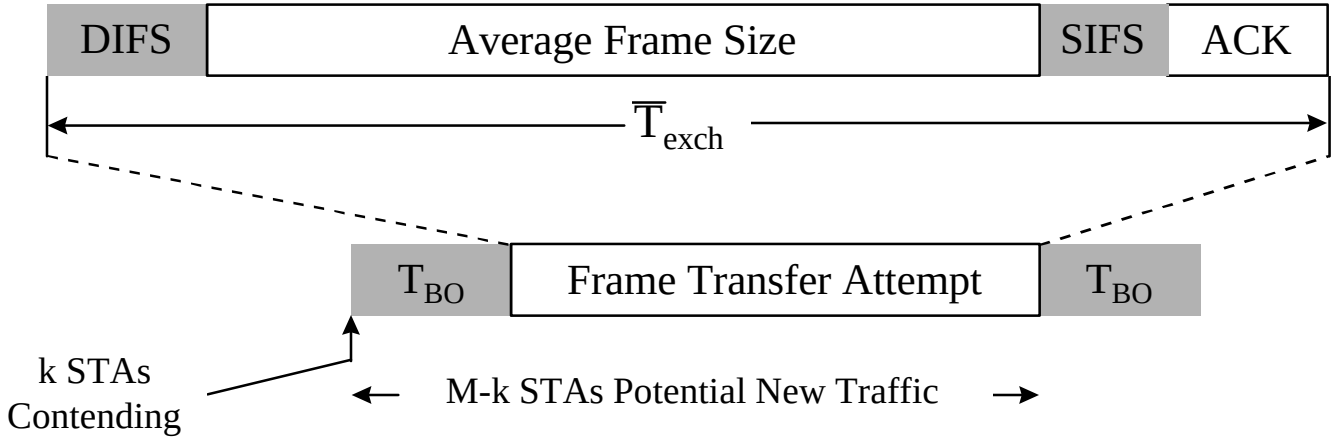
Method for Including Transmission Effects in Throughput Modeling

John H. Cafarella
MICRILOR, Inc.

Outline

- Baseline Formulation
  - Collisions-Only: M STAs, peer-to-peer
- Generalization to Include:
  - Interference effects
  - Non-uniform parameters
- Examples:
  - BSA Operation with High AP Traffic
  - Co-Channel Interference

Collision-Only Capacity Model: M Peer Stations; Frame Rate λ



$$\left(M-\bar{k}\right)\left(\bar{T}_{BO}+\overline{T_{exch}}\right)=\bar{P}_S$$

In equilibrium successful frame-transfer balances rate of new traffic

$$S=\left(M-\bar{k}\right)$$

Throughput (if not in equilibrium then k→0)

Following approach suggested by Bob O'Hara (D11_97/78)

Collision-Only Capacity Model: BackOff Equations

k>1

$$\overline{P}_{\_Collision} = \sum_{n=0}^{CW-1} \frac{k(CW-n)^{k-1}}{(CW+1)^k}$$

One STA selects slot n, all others select **later** slot

$$\overline{T}_{BO} = T_{slot} \sum_{n=1}^{CW-1} n \frac{k(CW-n)^{k-1}}{(CW+1)^k} = T_{slot}\overline{n}$$

T_{slot} times average slot number used

$$\overline{CW} = \frac{\sum_{n=3}^{2+N_{tries}} CW_n \left(1-\frac{P_S}{k}\right)^{n-3}}{\sum_{n=3}^{2+N_{tries}} \left(1-\frac{P_S}{k}\right)^{n-3}}$$

CW doubles each time attempt fails or blocked

$$_n = 2^n - 1, 3 \le n \le 7$$
$$= 255\ otherwise$$

Collision-Only Capacity Model: Self-Consistent Approximation

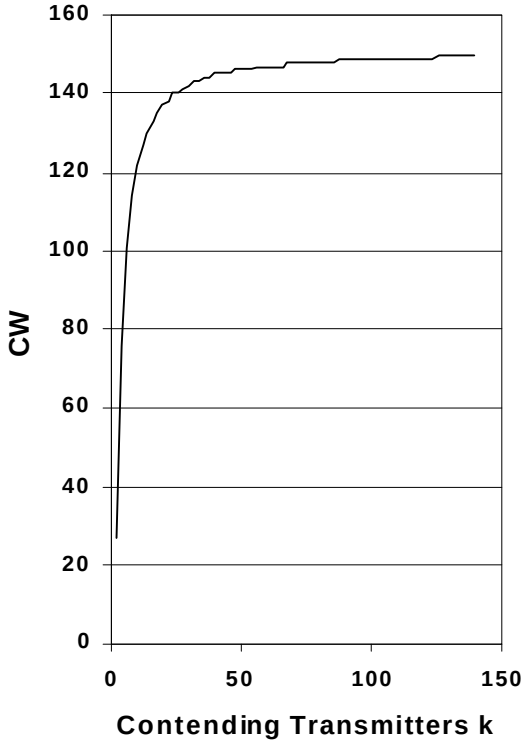
$$\overline{CW} = \frac{\sum_{n=3}^{2+Ntries} \left(2^n - 1\right)\left(1 - \frac{P_S}{k}\right)^{n-3}}{\sum_{n=3}^{2+Ntries} \left(1 - \frac{P_S}{k}\right)^{n-3}} \approx \frac{\sum_{n=3}^{2+Ntries} \left(2^n - 1\right)\left(1 - \frac{P_0}{k}\right)^{n-3}}{\sum_{n=3}^{2+Ntries} \left(1 - \frac{P_0}{k}\right)^{n-3}} \equiv CW(k)$$

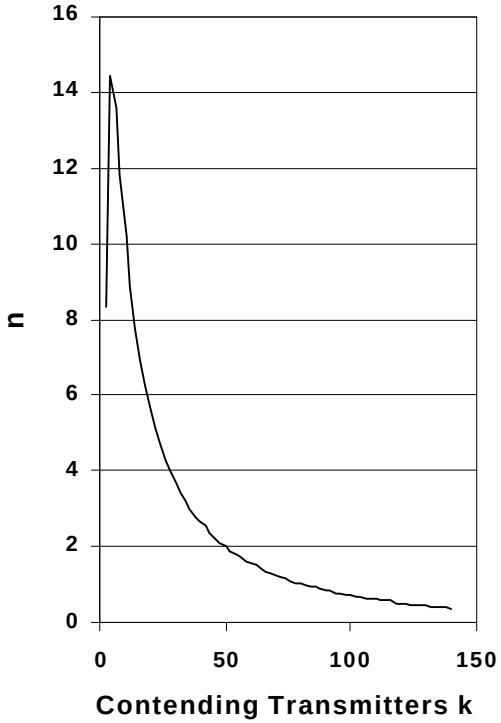
$$\overline{P}_{\_Collision} = \sum_{n=0}^{Int(CW(k))-1} \frac{k\left(CW(k) - n\right)^{k-1}}{\left(CW(k)+1\right)^{k}}$$

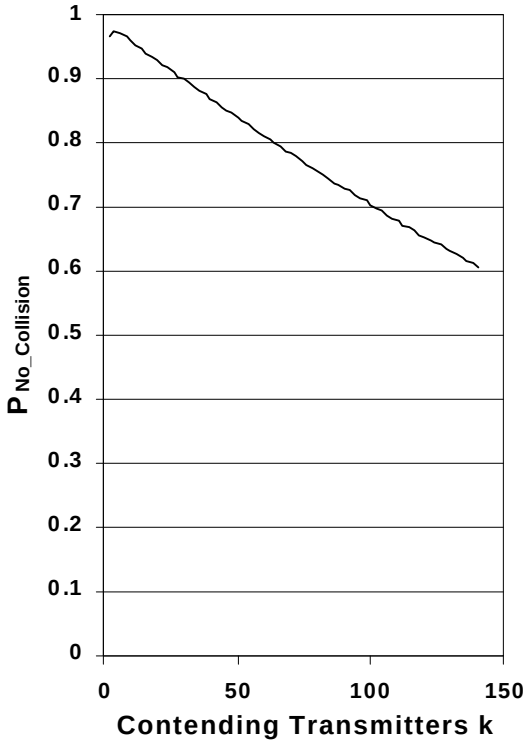
$$\overline{T}_{BO} = T_{slot} \sum_{n=1}^{Int(CW(k))-1} n \frac{k\left(CW(k) - n\right)^{k-1}}{\left(CW(k)+1\right)^{k}}$$

P_0 is guess at value of $P_{No\_Collision}$, but not critical; can be refined during iteration

Collision-Only Capacity Model: Parameters vs. Contending Units



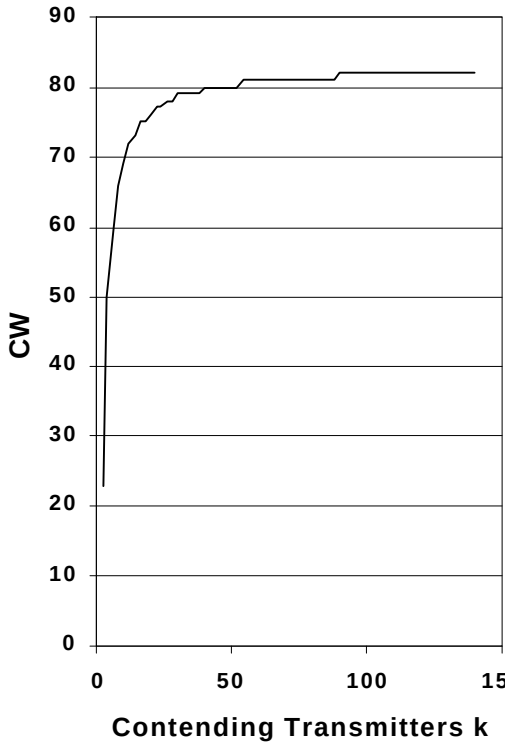


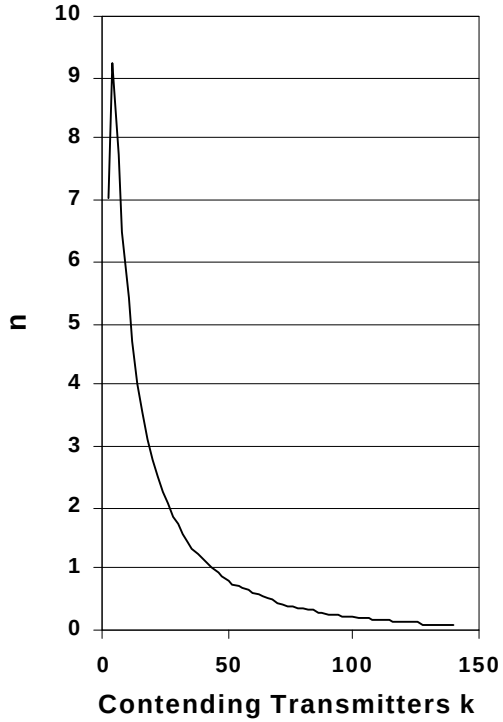


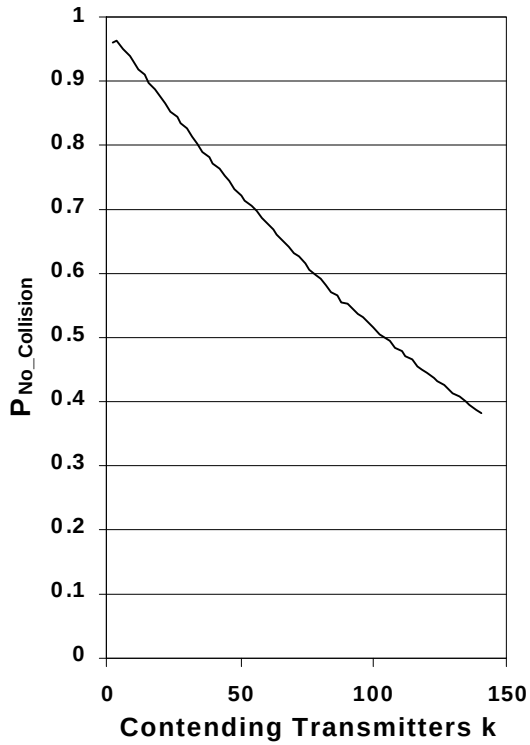
10 tries

Using P_0 =1

Collision-Only Capacity Model: Parameters vs. Contending Units







6 tries

Using P_0 =1

Collision-Only Capacity Model: Observations

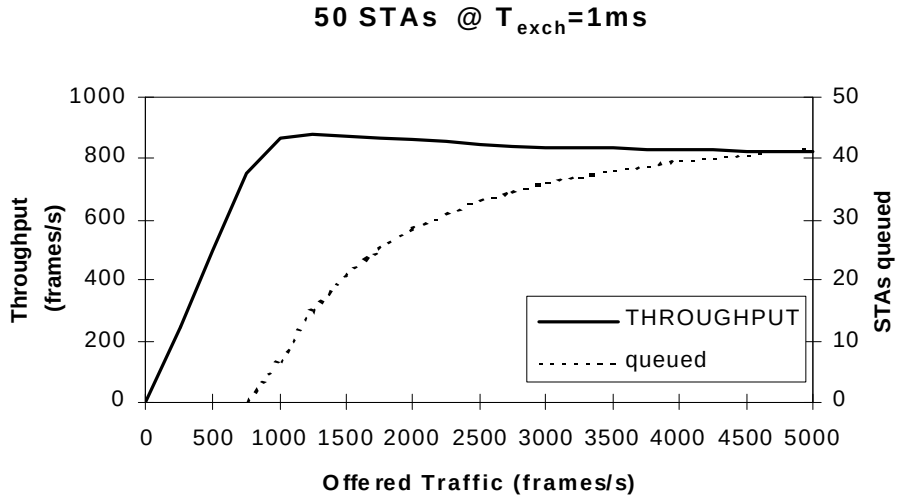
- Complex Interplay Among k, CW, $P_{No\_Collision}$, T_{BO}
- T_{BO} Is Not Critical For Large Frames
  - Mean slot number used goes to zero for large k
  - Justifies NTT/Lucent use of ½ aCWmin (D11_98/143)
- Probability of Collision Dominates Throughput

Collision-Only Capacity Model: Example

$$P_{\_Collision} = (M-k)\,(T_{BO}(k)+T_{exch})$$

$$= \sum_{n=0}^{Int(CW(k))-1} \frac{k\left(CW(k)-n\right)^{k-1}}{\left(CW(k)+1\right)^{k}}$$

$$S = \left(M-\bar{k}\right)$$



Generalization: Physical Effects & Non-uniformity

- Use P_S to Model Effects
  - $P_{No\_Collision}$ depends upon number of contending units (k)
  - P_X for "External" effects (ACI/CCI, Noise, etc.)
  - $P_S = P_{No\_Collision} \bullet P_X$
- Allow Unit-Specific Parameters
  - p_m is probability that unit m is ready to transmit
  - λ_m is "offered traffic" for unit m
  - $P_{No\_Collision} \bullet P_{Xm}$ is probability that unit m is successful

Generalization: Equations

- Detailed Balance for Equilibrium Traffic
- Aggregate Queued Traffic for Contention
- Average Contention Parameters

$$(1-p_m)\lambda_m\left(\overline{T} + \overline{T}\right) = p_m \frac{P_{\_Collision} P_{Xm}}{\{k,1\}_{\max}}$$

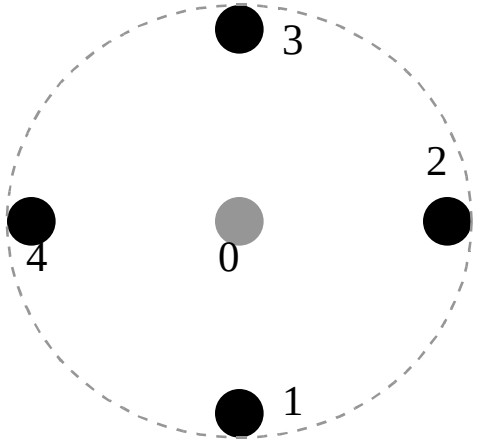
In equilibrium successful frame-transfer balances rate of new traffic per unit

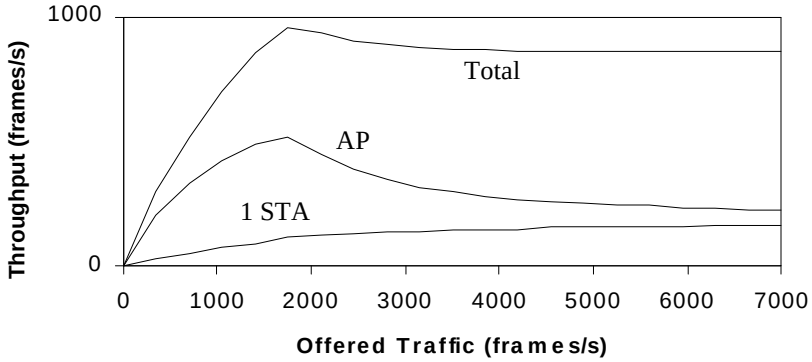
$$k = \sum_m p_m \rightarrow \overline{P}_{\_Collision}, \overline{T}_{BO}, \overline{CW}$$

$$S = \sum_m (1-p_m)\lambda_m$$

Application to BSA with AP

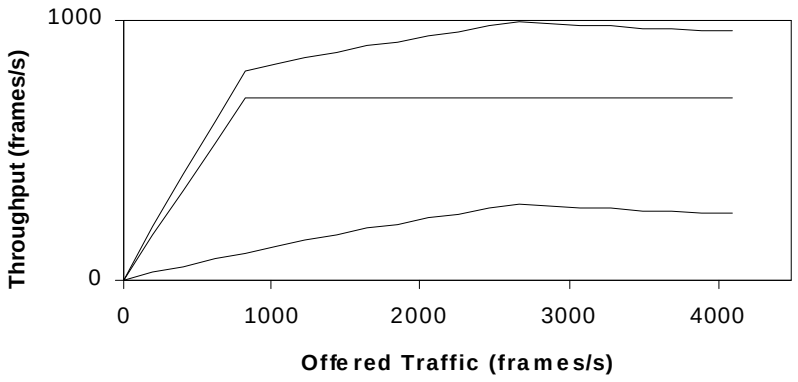
- λ Frame/s per STA
- 10 λ Frame/s per AP
- No Peer-to-Peer Traffic
-
- Can't Use Contention for Disparate Traffic
- 802.11 is "Fair"





Application to BSA with AP

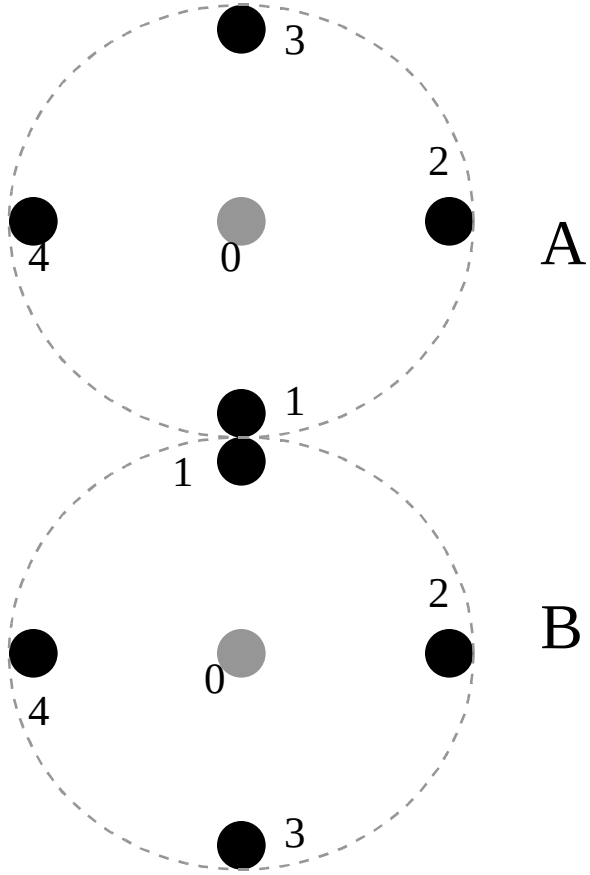
- λ Frame/s per STA
- 10 λ Frame/s per AP
- Operate with .7 Duty Factor for AP Only
- STAs Contend with STAs for .3 Duty Factor
- Maintains 10:4 Ratio of AP/STA Traffic at Peak



Assume STA generation suspended during CFI to avoid modeling the resumption transient

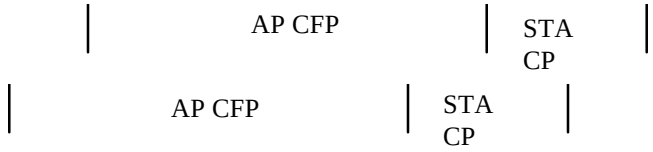
Application to BSA CCI with Single Code

- λ Frame/s per STA
- 10 λ Frame/s per AP
- R^2 Propagation Loss
- Operate with .7 Duty Factor for AP Only
- STAs Contend with STAs for .3 Duty Factor



Application to BSA CCI with Single Code

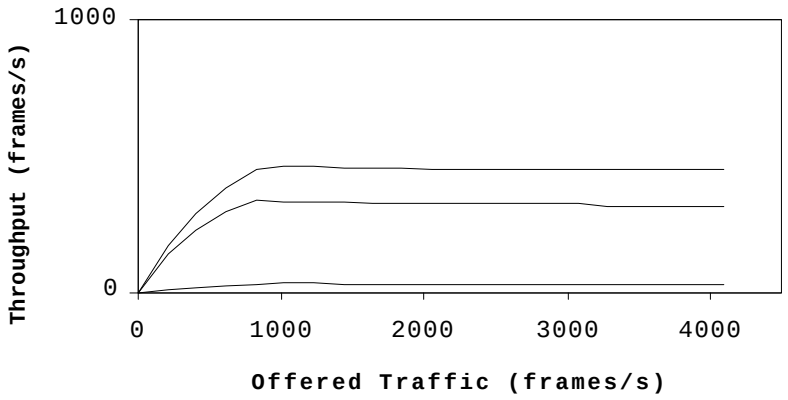
- BSAs Unsynchronized
- Probabilities:
  - .7 that AP sees other AP
  - .3 that AP sees STAs in other BSA
  - .7 that STAs see other AP
  - .3 that STAs see STAs in other BSA
- Average Conditional Throughput



Application to BSA CCI with Single Code

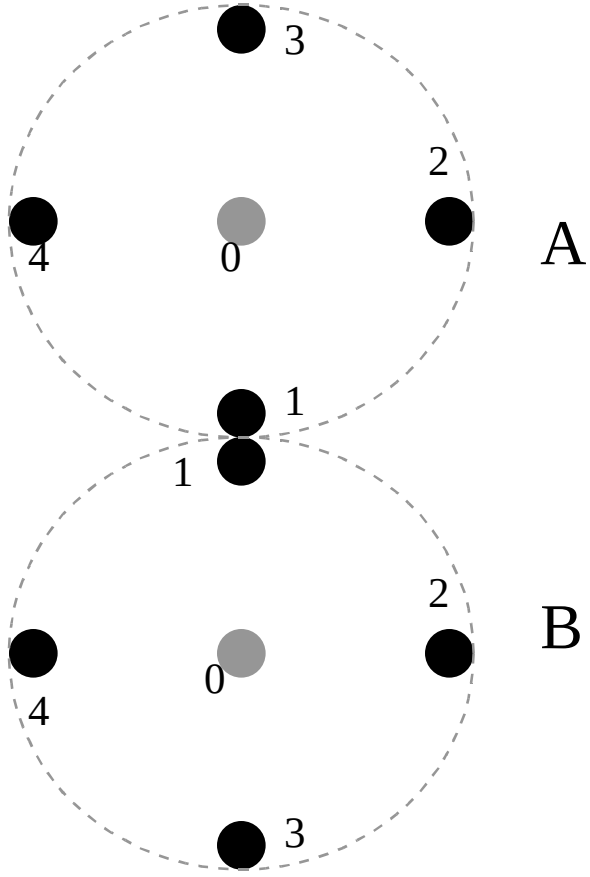
- What IF BSAs Synchronized?
-

AP CFP	STA CP	
AP CFP	STA CP	



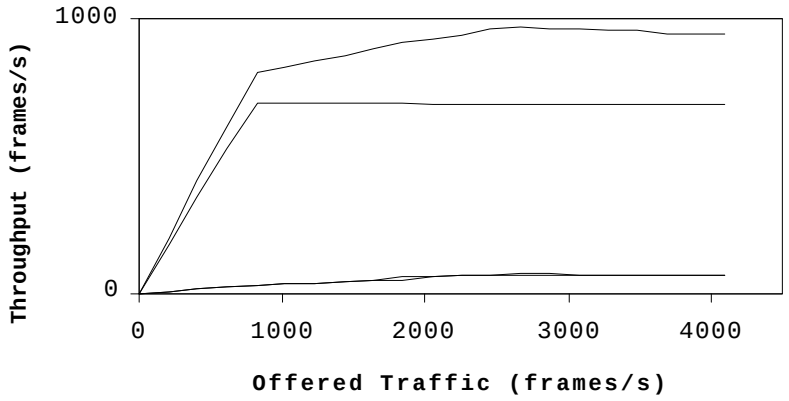
Application to BSA CCI with Code Channels

- λ Frame/s per STA
- 10 λ Frame/s per AP
- R^2 Propagation Loss
  - Units A1 & B1 have near/far problem
- Operate with .7 Duty Factor for AP Only
- STAs Contend with STAs for .3 Duty Factor

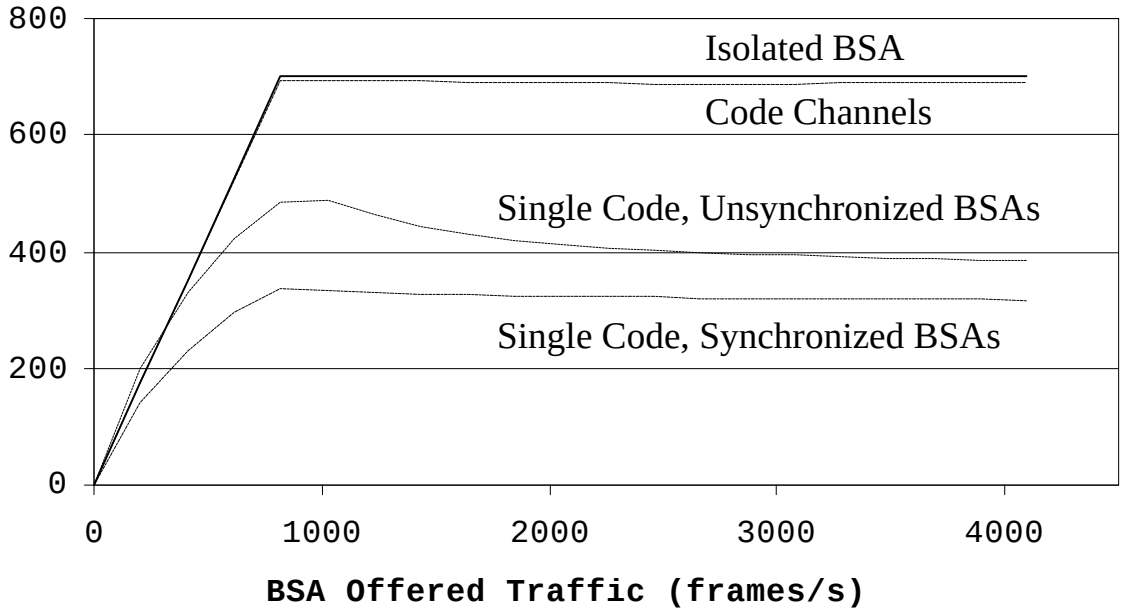


Application to BSA CCI with Code Channels

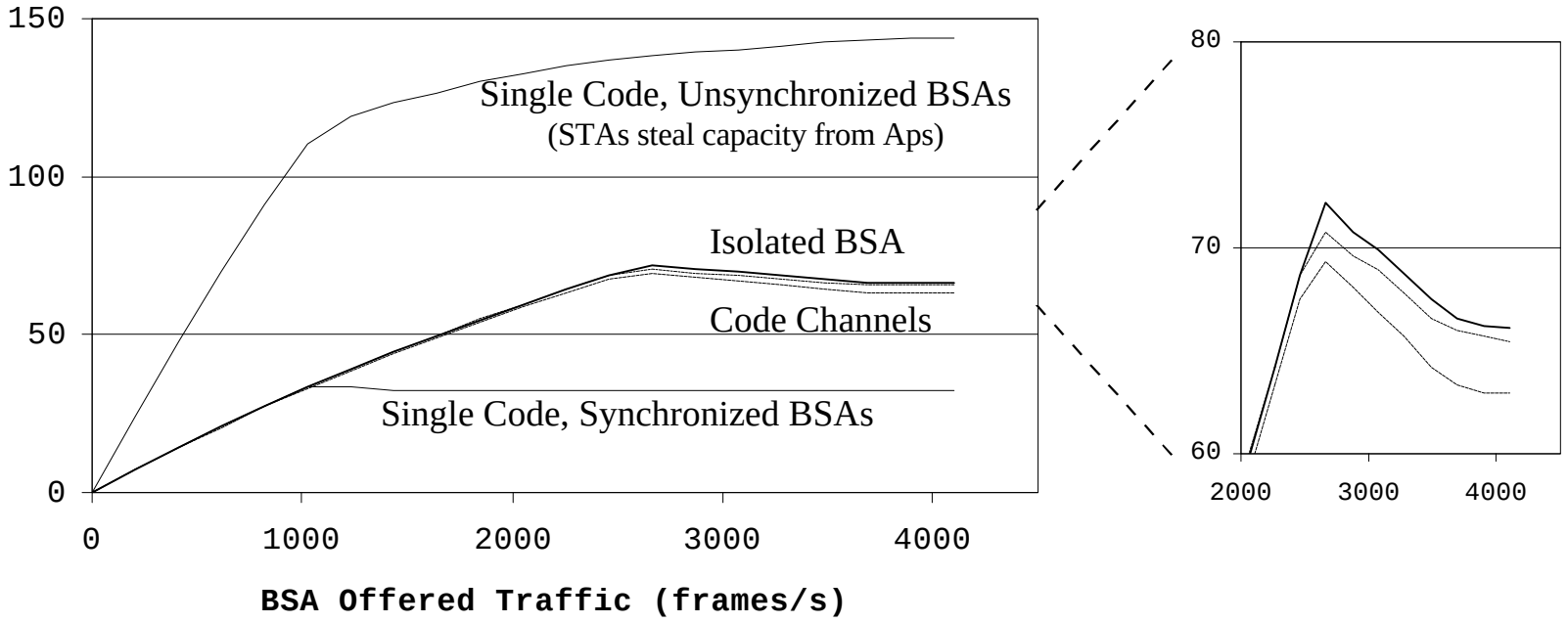
- Frame Reception at A1 Blocked if B1 Transmitting
- ACK Reception Blocked at A1 if B1 Transmitting
- B1 random with Respect to A1



Access Point Throughput



Single STA Throughput



Summary

- Generalized Formulation Captures "Physics"
- Equations Simple to Solve by Iteration
- Applications Demonstrate
  - 802.11 MAC "Fairness"
  - AP Must Use Contention-Free Interval (if high traffic)
  - Code Channelization Can Isolate BSAs to Provide More Nearly Full Capacity per BSA
  - Single Code Operation Enables STAs to