On Using Battery State for Medium Access Control in Ad hoc Wireless Networks - “BAMAC”

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Energy Management in Ad hoc Wireless Networks

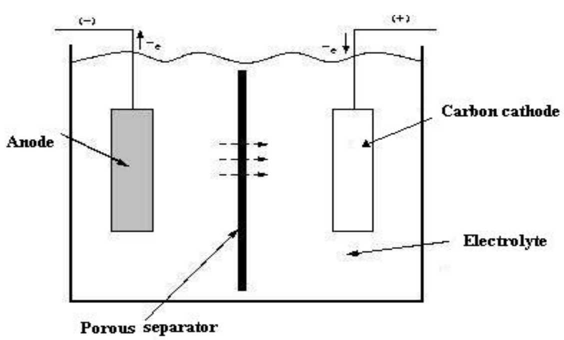
Energy management: Process of managing energy resources by means of controlling the battery discharge, adjusting transmission power, and scheduling power sources, so as to increase the lifetime of an Ad hoc wireless network

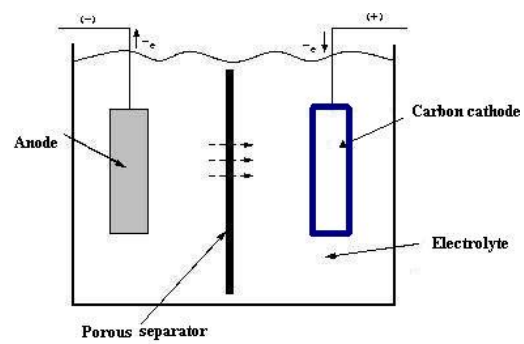
Why energy management? Fig

- Limited energy reserve
- Difficulties in replacing the batteries
- Lack of central coordination – relay nodes?
- Constraints on the battery – weight-capacity relationship
- Selection of optimal transmission power
- Channel utilization for CDMA based system

Battery-related Terms

- **What is a battery ?**
- **Characterizing batteries**
  - **Voltages (open circuit, operating, and cut-off)**
  - **Capacities - Rate capacity effect and Recovery capacity effect**
    - o **Theoretical (T)**
    - o **Nominal/standard (N)**
    - o **Actual**

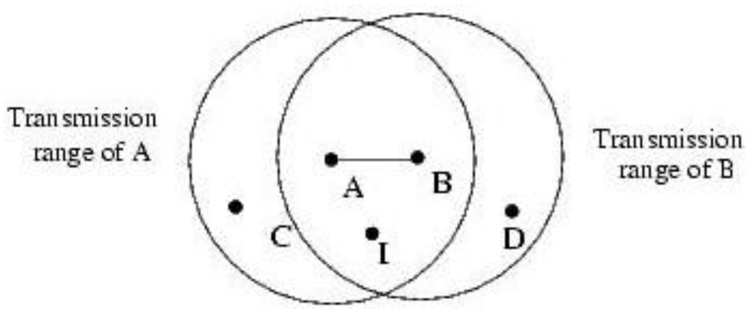




BAMAC(*k*) MAC Protocol

- Inspiration!
- Battery-aware MAC protocol (BAMAC(*k*))
  - Main Idea – MAC + Battery information
  - Exploiting recovery state of the batteries
  - Uniform discharge of the batteries
  - Nodes are scheduled in a near round-robin manner
  - MAC protocol – "The higher the remaining battery capacity, the lower the back-off period."
- Discrete-time Markov chain analysis of battery lifetime
- Comparative study of IEEE 802.11 and DWOP with BAMAC and Simulation Vs. Theoretical Analysis
- Analysis of the factor '*k*'

Illustration of Battery Table



Source A — **Destination B**

STEP 1: RTS → Receive RTS

BT(A)

Nodes	Battery volts (V)	NC	Usage time (ms)
A	4.5	240	10

BT(I)

Nodes	Battery volts (V)	NC	Usage time (ms)
A	4.5	240	10
I	4	230	5

BT(B)

Nodes	Battery volts (V)	NC	Usage time (ms)
B	5	250	0
A	4.5	245	10

STEP 2: Receive CTS ← CTS

BT(A)

Nodes	Battery volts (V)	NC	Usage time (ms)
B	5	250	0
A	4.5	240	10

BT(I)

Nodes	Battery volts (V)	NC	Usage time (ms)
B	5	250	0
A	4.5	240	10
I	4	230	5

BT(B)

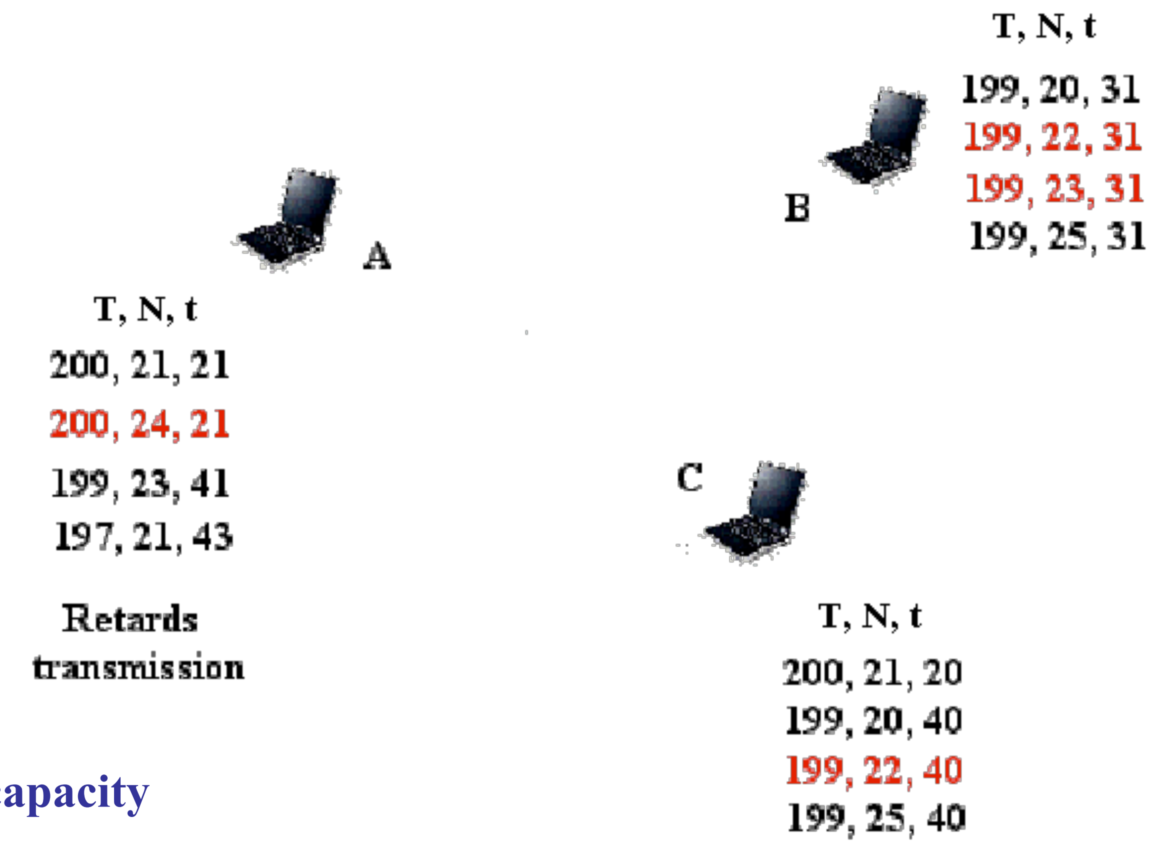
Nodes	Battery volts (V)	NC	Usage time (ms)
B	5	250	0
A	4.5	245	10

Back-off Calculation

$$Back-off = Uniform\left[0,\left(2^{x} \times CW_{\min}\right)-1\right] \times rank \times \left(T_{SIFS} + T_{DIFS} + T_{t}\right)$$

- Cw_{min} – Minimum size of the contention window
- *rank* – Position of that entry in the battery
- T_{SIFS}+T_{DIFS} – SIFS and DIFS duration as in IEEE 802.11
- T_t – Successful packet transmission time, including RTS-CTS-Data-ACK
- *x* – Number of transmission attempts made for a packet
- Uniform(*i,j*) – random number distributed uniformly between *i* and *j*
- *n* - Number of neighbors

Illustration of BAMAC



T- Theoretical capacity

N- Nominal capacity

t- Time of transmission

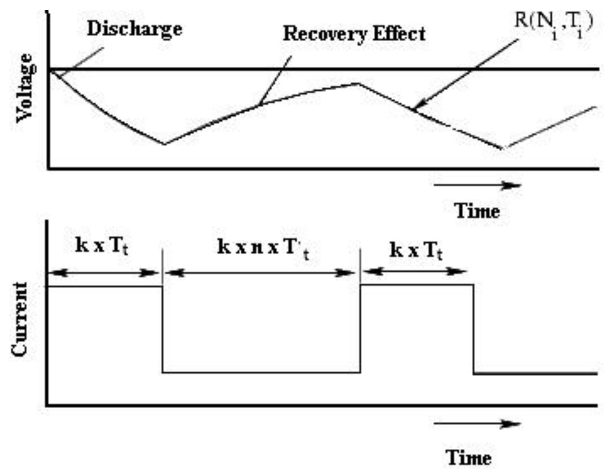
Modeling the Batteries Using Discrete-Time Markov Chain With Probabilistic Recovery

Notations used:

- T - Initial theoretical capacity ; N - Initial nominal capacity
- T_i - Theoretical capacity at time unit *I;* N_i - Nominal capacity at time unit *i*
- Tx - Transmission state ; Rx - Recovery state
- $R_{Ni,Ti}$ - Probability to recover one charge unit

$$R_{N_i,T_i} = \begin{cases} e^{-g(N-N_1)-\Phi(T_i)} & \text{if } 1 \le N_i \le N,\ 1 \le T_i \le T \\ 0 & \text{otherwise} \end{cases}$$

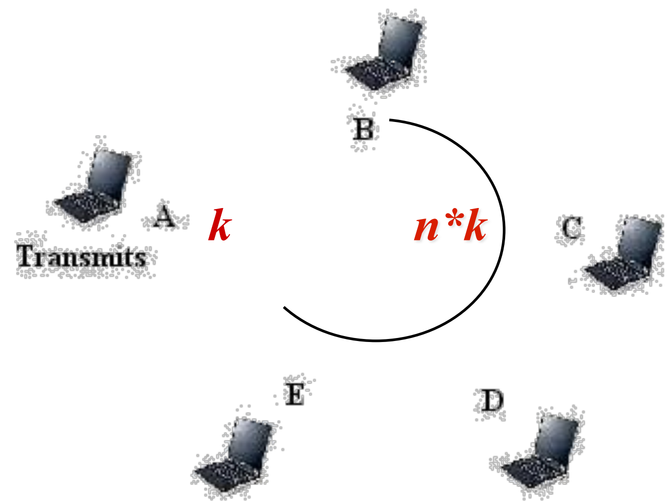
Illustration of battery discharge of nodes using BAMAC(k)

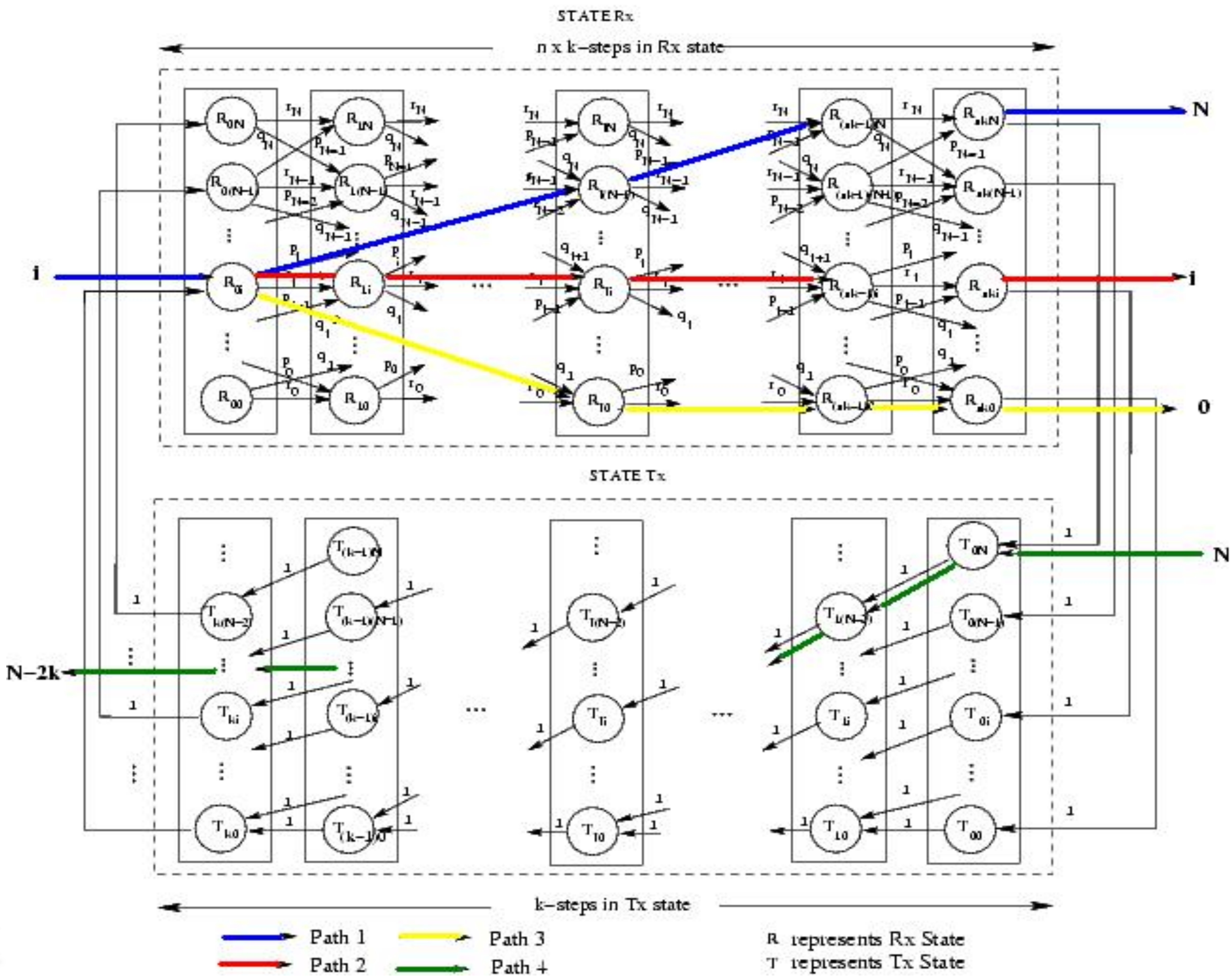


T_i	$\phi(T_i)$
200 to 196	0.0
195 to 101	0.0025
100 to 6	0.008
5 to 0	15.6

Average discharge time = $k*T_t$

Average recovery time = $n*k*T_t$




STATE Rx
n x k−steps in Rx state
STATE Tx
k−steps in Tx state
i
N
i
0
N
N−2k
Path 1
Path 2
Path 3
Path 4
R represents Rx State
T represents Tx State

PM

Probability Matrices

$$Rx = rec^{nk}\begin{vmatrix} 1 & 0 & 0 & 0 & \dots & 0 & 0 \\ q_1 & r_1 & p_1 & 0 & \dots & 0 & 0 \\ 0 & q_2 & r_2 & p_2 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots & \vdots \\ 0 & \dots & 0 & q_{N-2} & r_{N-2} & p_{N-2} & 0 \\ 0 & 0 & \dots & 0 & q_{N-1} & r_{N-1} & p_{N-1} \\ 0 & 0 & 0 & \dots & 0 & q_N & r_N \end{vmatrix}^{nk}$$

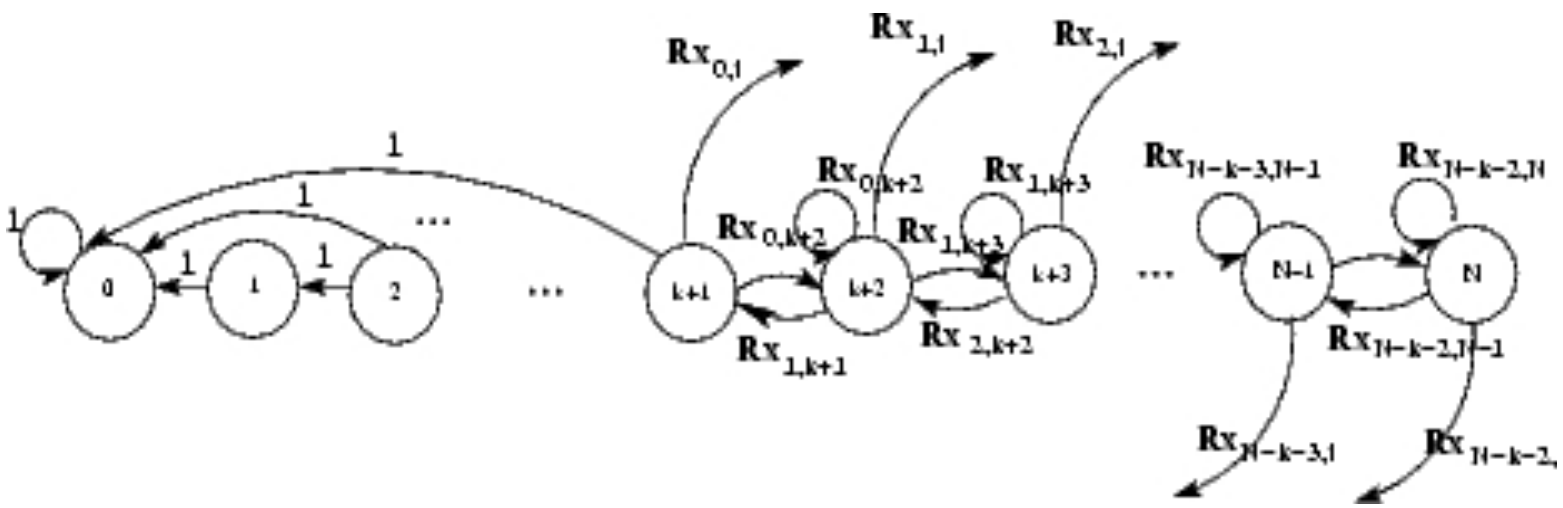
$$Tx = Trans^k\begin{vmatrix} 1 & 0 & 0 & \dots & 0 & 0 \\ 1 & 0 & 0 & \dots & 0 & 0 \\ 1 & 0 & 0 & \dots & 0 & 0 \\ 0 & 1 & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \dots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \dots & \vdots & \vdots \\ 0 & \dots & 1 & 0 & 0 & 0 \\ 0 & \dots & 0 & 1 & 0 & 0 \end{vmatrix}^{k}$$

$$P = Tx * Rx = Trans^k * rec^{nk}$$

$$P = \begin{vmatrix} 1 & 0 & \dots & 0 & 0 \\ 1 & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ 1 & 0 & \dots & 0 & 0 \\ Rx_{0,0} & Rx_{0,1} & \dots & Rx_{0,N-1} & Rx_{0,N} \\ Rx_{1,0} & Rx_{1,1} & \dots & Rx_{1,N-1} & Rx_{1,N} \\ \vdots & \vdots & \dots & \vdots & \vdots \\ Rx_{N-k-3,0} & Rx_{N-k-3,1} & \dots & Rx_{N-k-3,N-1} & Rx_{N-k-3,N} \\ Rx_{N-k-2,0} & Rx_{N-k-2,1} & \dots & Rx_{N-k-2,N-1} & Rx_{N-k-2,N} \end{vmatrix}$$

Fig

Final Markov Model Representing Battery Behavior



Steps to Calculate Time Duration of the Markov Model to Remain in Transient States

Step 1: Given any probability matrix P, Calculate matrix $Q = \lfloor Q_{(i,j)} \rfloor$, where i and j represent only the transient states . In our protocol $Q_{(i,j)} = P_{(i+1,j+1)}$

Step 2: Calculate matrix $M=(I-Q)-1$, where I is the identity matrix.

Step 3: Now, $M_{(i,j)}$ represents the total number of times a battery enters state j if the starting state is I and Δt is the time duration the Markov model spends in state j once it enters it.

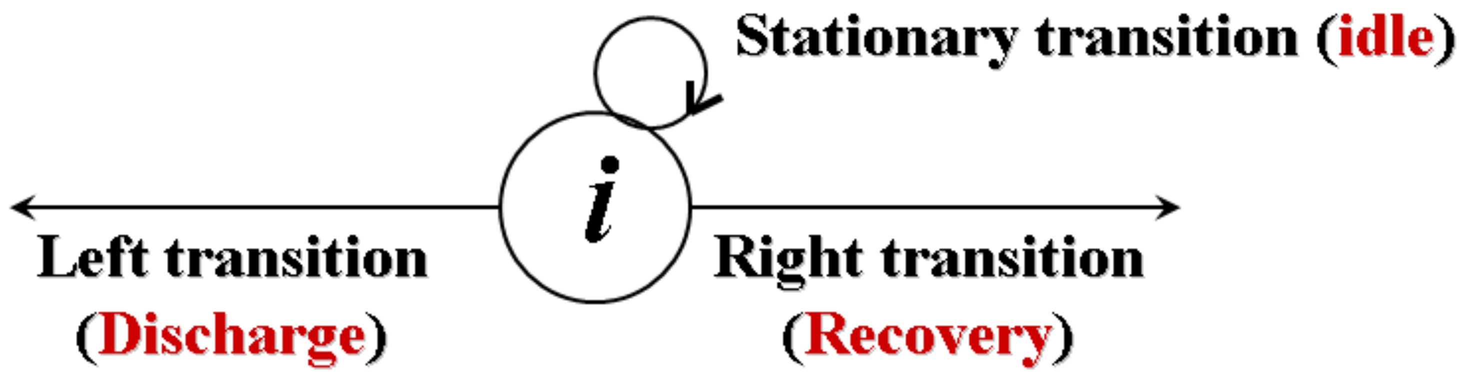
$$M = \begin{vmatrix} 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 \\ Z_{0,0} & Z_{0,1} & \cdots & Z_{0,N-1} & Z_{0,N} \\ Z_{1,0} & Z_{1,1} & \cdots & Z_{1,N-1} & Z_{1,N} \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ Z_{N-k-3,0} & Z_{N-k-3,1} & \cdots & Z_{N-k-3,N-1} & Z_{N-k-3,N} \\ Z_{N-k-2,0} & Z_{N-k-2,1} & \cdots & Z_{N-k-2,N-1} & Z_{N-k-2,N} \end{vmatrix}$$

$$Z_{(i,j)} = \begin{cases} 1 - Rx_{i,j} & \text{if } i = j \\ -Rx_{i,j} & \text{otherwise} \end{cases}$$

Tactive **– Maximum Life time of a battery of a node**

$$T_{active} = \sum_{i=1}^{i=N} M_{N,i}$$

Battery lifetime calculation



$$T_{left} = \sum_{i=1}^{N} \times \sum_{j=1}^{i-1} P_{i,j}$$

Total number of transmissions = $\dfrac{2 \times T_{left}}{3}$

Performance Analysis

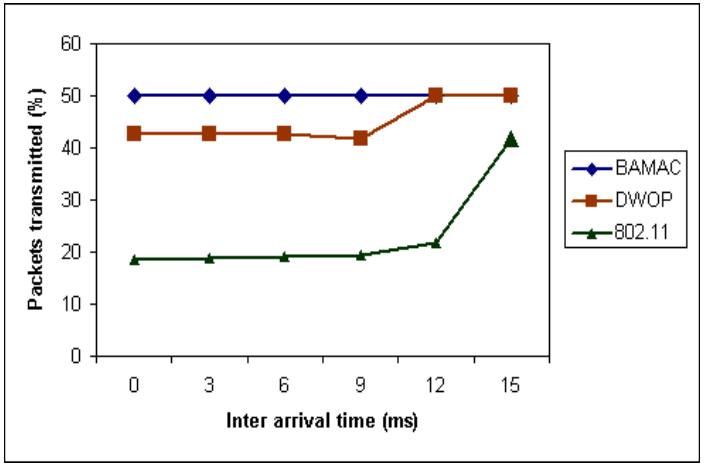
- **GloMoSim**
- **Simulation parameters**

Simulation area	***2000m x 2000m***
Number of nodes	***10-40***
Transmission power	***12dB***
Channel bandwidth	***2Mbps***
Routing protocol	***DSR***
Path loss model	***Two-Ray***
Battery Parameters	***T=2000; N=250; g=0.05***

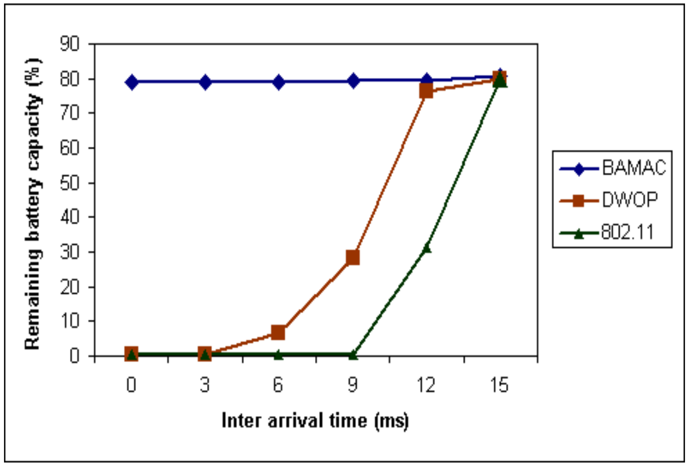
- **Transmission – *2*; Reception – *1* ; idle – *0*; Listening - *0***
- **A small battery to power up during idle mode**
- **Existence of SBS – state of the battery**

Results for BAMAC(*k*)

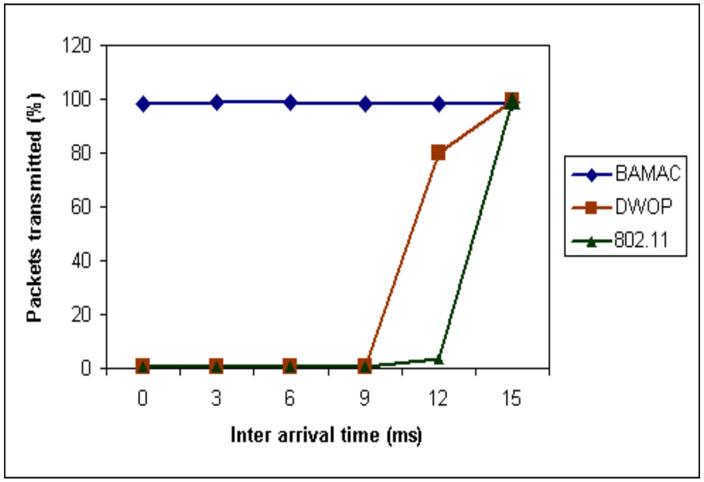
Number of packets transmitted

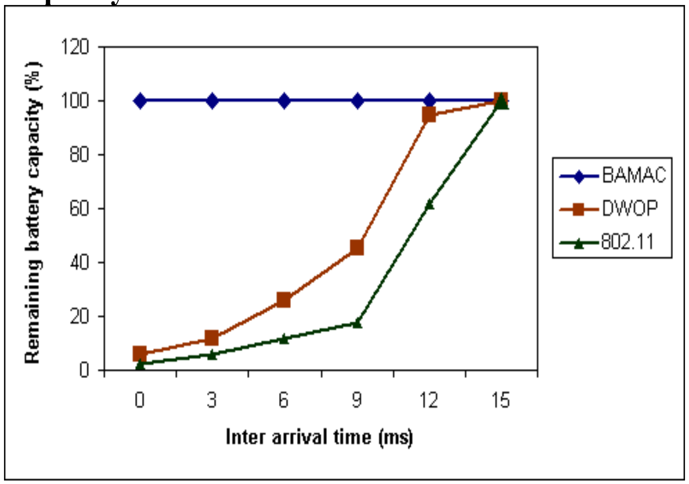


Remaining battery charge



Infinite theoretical capacity





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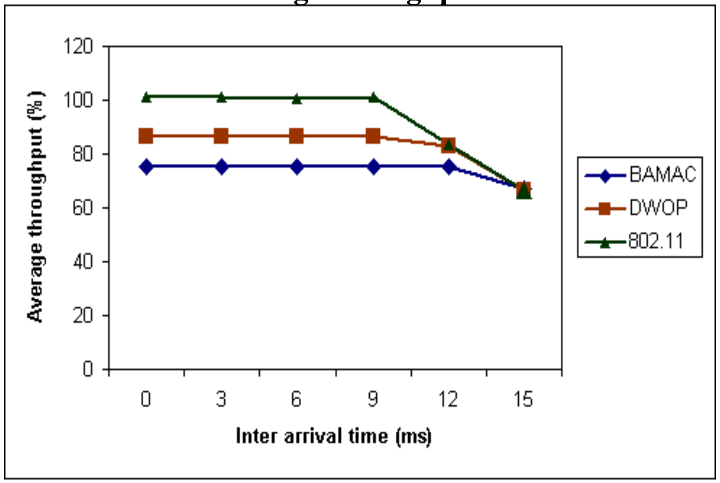
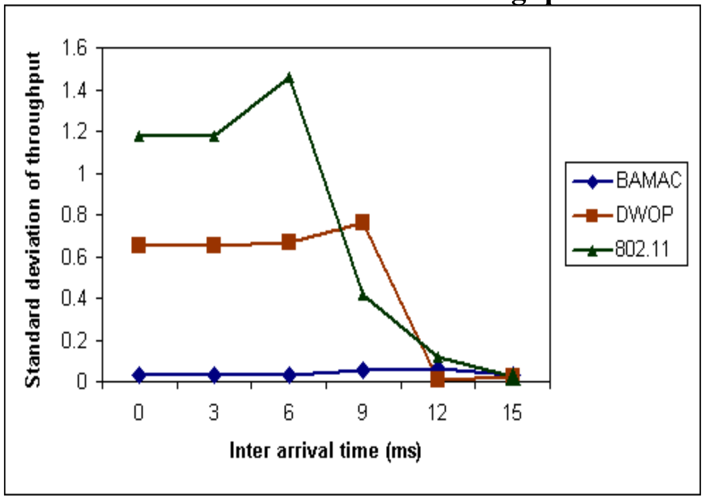
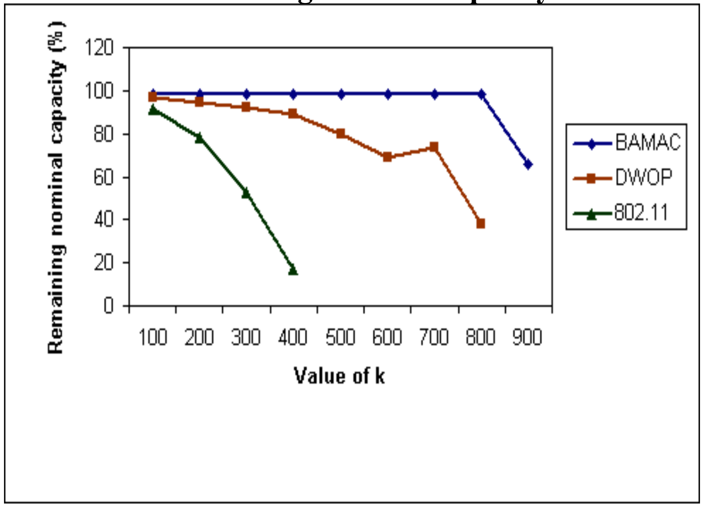
Average throughput



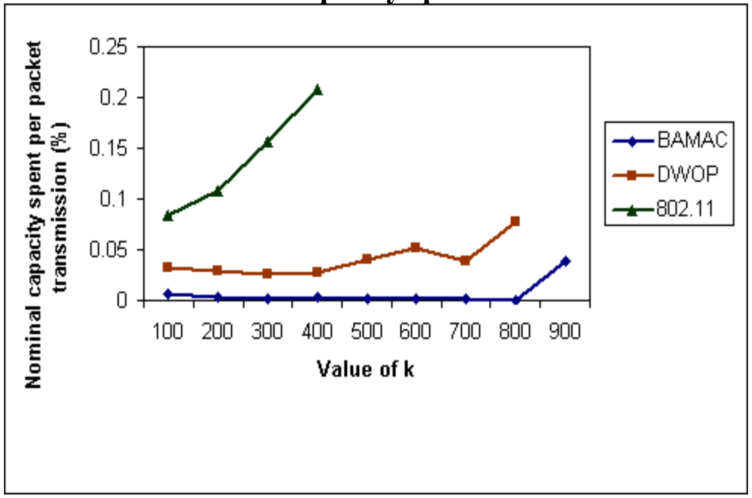
Standard deviation of throughput



Remaining nominal capacity



Nominal capacity spent



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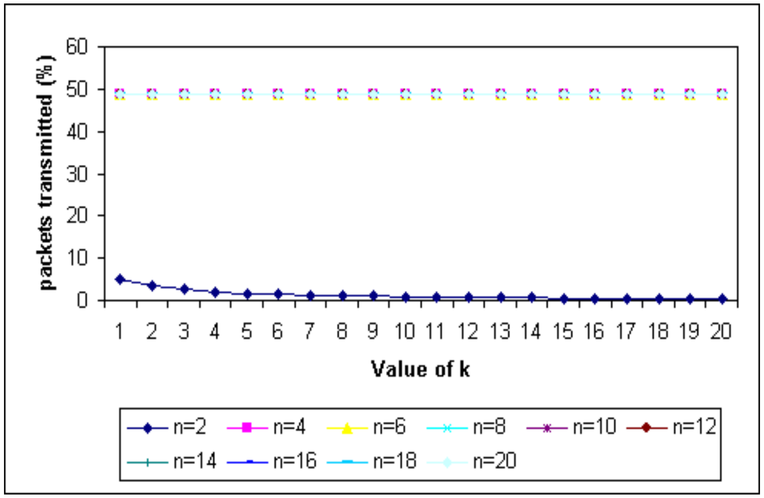
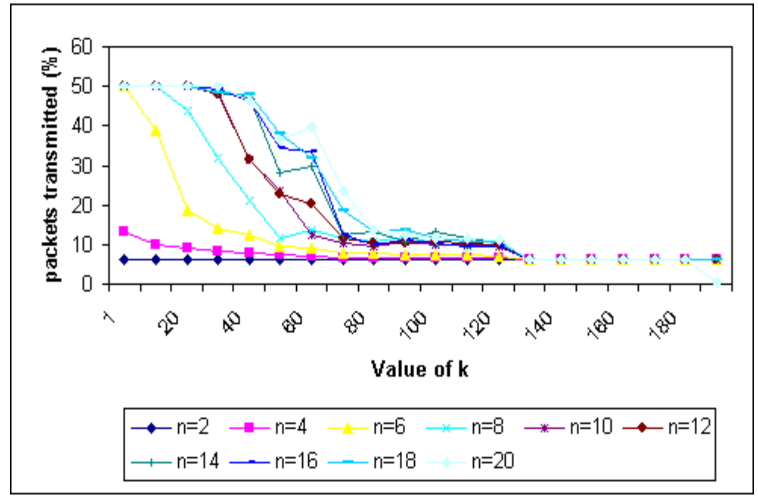
Simulation results

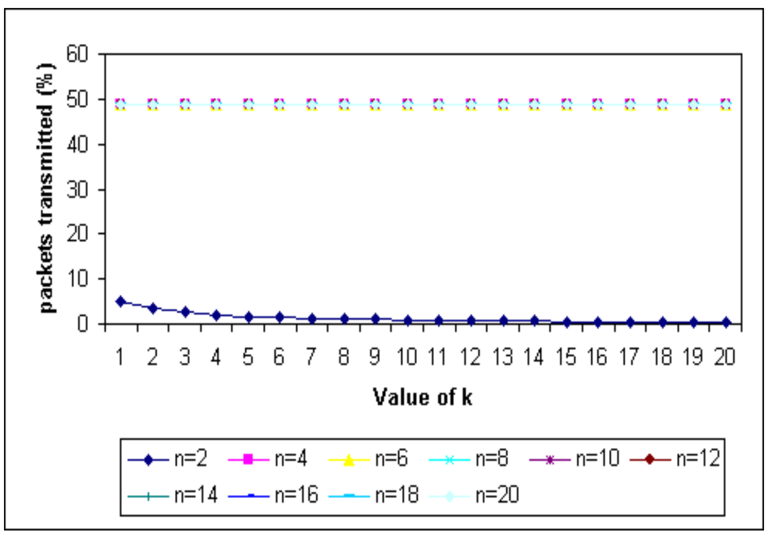
Packets transmitted for 1>k>20

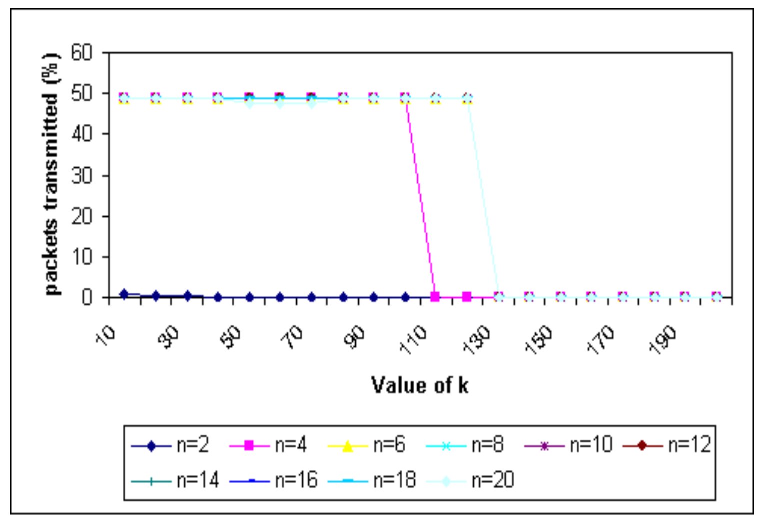


Packets transmitted for 1>k>250



Theoretical results





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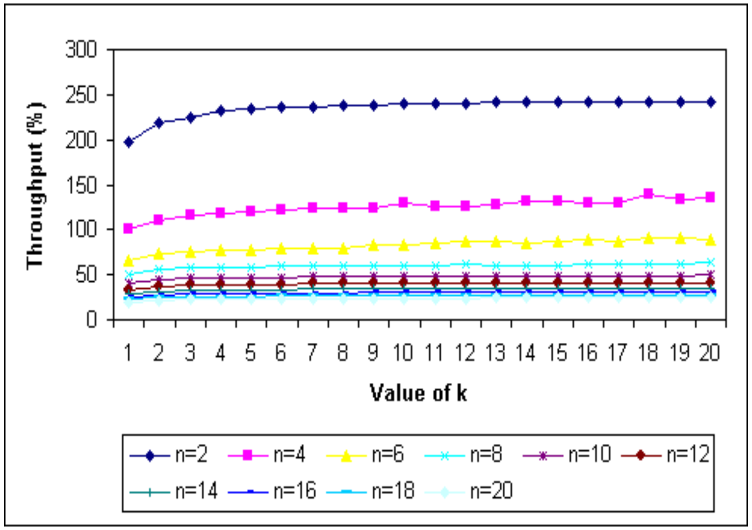
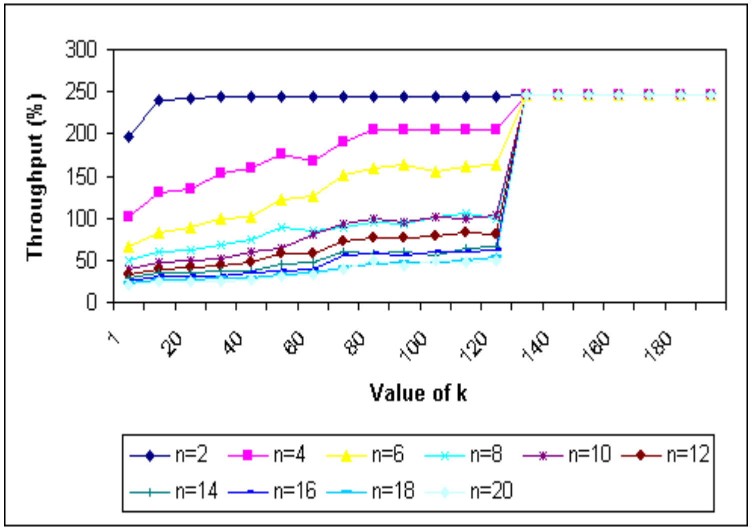
Throughput for 1>k>20



Throughput for 1>k>250



Conclusion and Future Perspective

- What is our contribution?
- BAMAC(*k*) – Battery Aware MAC protocol
- Modeling of batteries using Discrete-time Markov chain analysis: Battery Lifetime Calculation
- Analysis of the factor "*k*"
- Performance Analysis
- Future perspective
- Finding optimal *K* Value
- Relaxing the basic assumptions
  - Sleep mode instead of idle mode!
  - Absence of an additional small battery
- Heterogeneous battery technologies
- Presence of real-time data traffic
- Generalized Markov model
- Develop a generalized tool for calculating battery life time for all MAC protocols

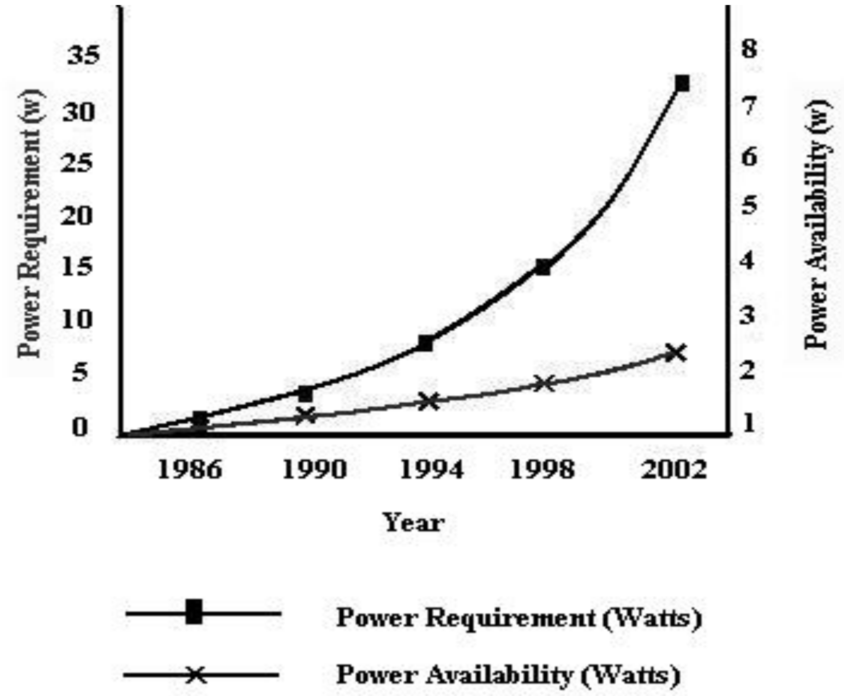
THANK YOU

IIT Madras

IBM-IRL India

DST Delhi, India

Increasing Gap Between Power Requirement And Availability



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K. Lahiri, A. Ragunathan, S. Dey, and D. Panigrahi, " Battery-DrivenSystem Design: A New Frontier in low-Power Design," *Proceedings of ASP-DAC/VLSI Design 2002.*