Energy-Aware Distributed Multimedia Systems

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Outline

- **Introduction**
- **Concurrent Subband Modulation and Adaptive Decoding**
- **Energy-aware MPEG-4 FGS Video Streaming**
- **Power-aware Source Routing in MANETs**
- **Summary**

Concurrent Subband Modulation and Adaptive Decoding

- Consider an ad hoc network of battery-powered mobile hosts
- Consider any point-to-point link between a sender and a receiver host

- Assume that in each time slot, the receiver provides an estimate of the channel characteristics to the transmitter as well as information about its remaining energy level
- Using this data and information about the remaining energy of the transmitter itself, the transmitter solves an optimization problem that would yield the energy optimal set of modulation levels and the transmit power level
- Given the set of transmitter parameters, the receiver must minimize its own energy consumption by selecting its Viterbi decoder length
- Constraints are the minimum throughput and the maximum bit-error-rate

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QAM and Adaptive Modulation

- In QAM, the bit error rate is strong function of the Signal-to-Noise ratio and the number of constellation points

$$BER = {}^{4}\!/_{b} \cdot \left(1 - \frac{1}{2^{b/2}}\right) \cdot Q\left(\sqrt{3 \cdot \frac{SNR}{2^{b}-1}}\right)$$

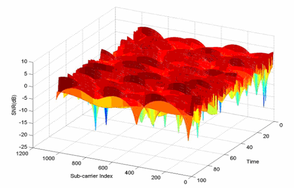
BER: Bit-Error-Rate

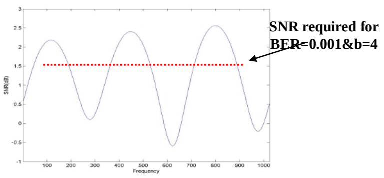
SNR: Received Signal-to-Noise Ratio

b : Number of bits per constellation point

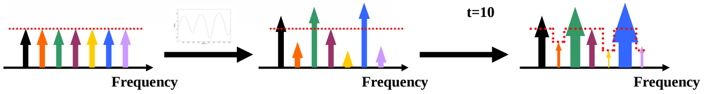
Q : Normal cumulative probability function

- Key Idea : Choose the number of constellation points as a function of SNR in each sub-carrier



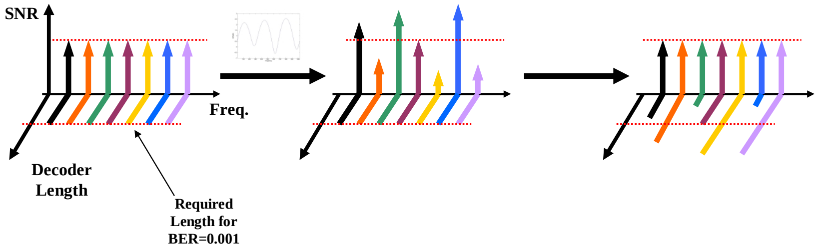


Channel Characteristic for t=10



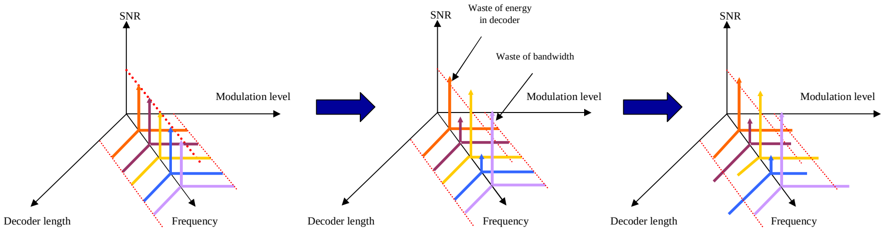
Convolutional Codes and Adaptive Decoding

- Convolutional codes
  - A Family of Forward Error Controlling codes
  - Based on convolution of input data stream and two or more constant bit streams
- Key Idea : Adaptively change the decoding length based on received SNR for each sub-carrier



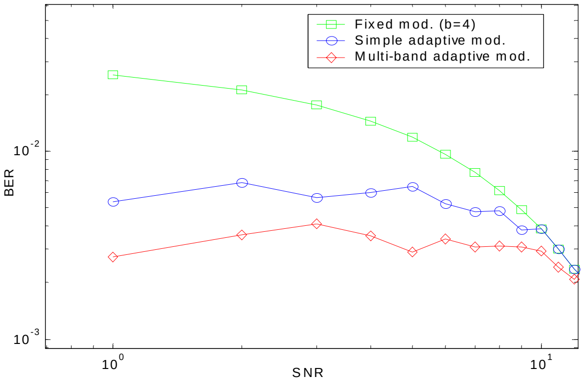
Concurrent Adaptive Modulation and Decoding

- Using both adaptive modulation and decoding, i.e., having two degrees of freedom, the overall system energy can be reduced while keeping the average throughput constant
- Minimize the energy consumption per bit in the transmitter and the receiver of a wireless link while maintaining a minimum throughput and a maximum bit-error-rate
  - Transmitter sets the set of modulation levels for all subbands and its transmit power level
  - Receiver sets its Viterbi decoding length for each subband



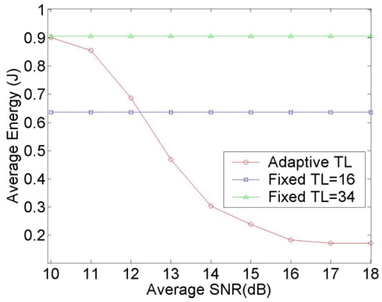
Results of Subband Modulation

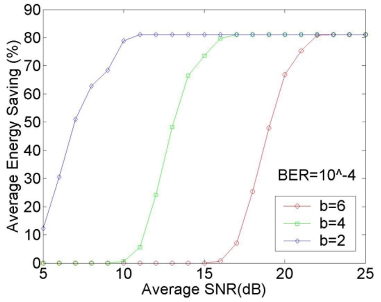
- A fixed decoder is used and the effect of subband modulation based on the estimated channel characteristic is reported



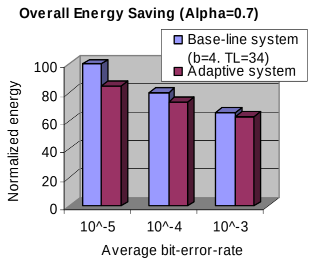
Results of Adaptive Decoding

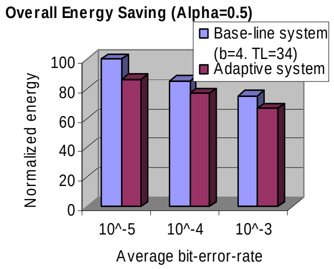
- A fixed modulation level is chosen and the effect of variable decoding length on average energy consumption is studied

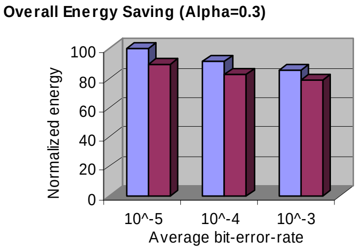




Results: Total Energy Consumption


Overall Energy Saving (Alpha=0.7)


Overall Energy Saving (Alpha=0.5)


Overall Energy Saving (Alpha=0.3)

$$E_{avg} = \alpha \cdot E_{Transmit} + (1-\alpha) \cdot E_{Receive}$$

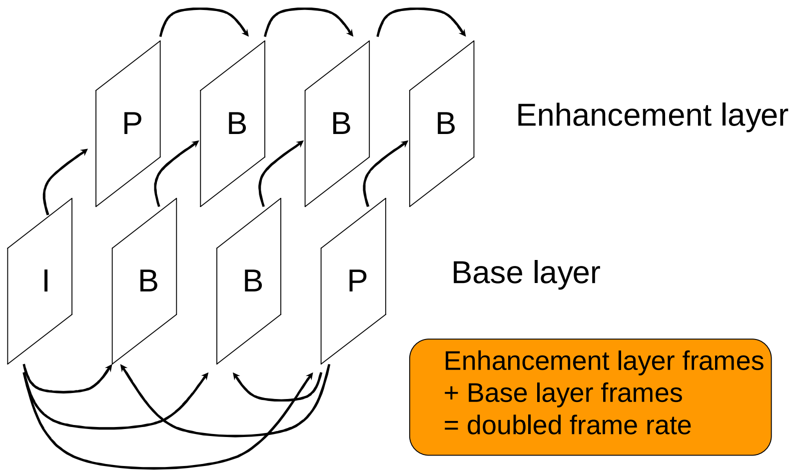
- **The base-line system is a system without any adaptive parameter except for the transmit power. Transmit power in base-line system is adaptively changed based on the average BER required on the receiver side. The optimized system refers to the adaptive transceiver proposed here**

Wireless Video Streaming

- **For mobile wireless video streaming two factors should be considered: high video quality and long service time**
- **Stable channel for real-time operation**
  - **Video quality degradation due to channel congestion or error rate**
  - **Scalable coding technique to be adaptive channel bandwidth variation**
- **Power-aware operation so as to increase the lifetime of battery-powered mobile system**
  - **Optimal energy consumption to meet the required video quality**
- **Scalable video coding is required to be adaptive to channel variation**
  - **a base layer (BL) + an enhancement layer (EL)**

Temporal Scalability

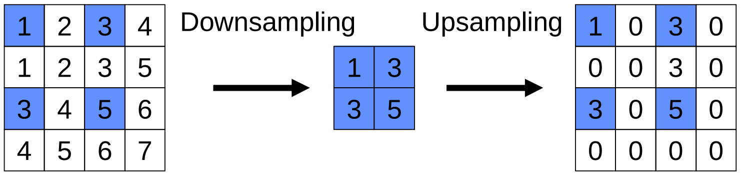
- **Enhancement layer introduces a layer of P and B frames**



Enhancement layer frames
+ Base layer frames
= doubled frame rate

Spatial Scalability

- **Code a video into two layers at different spatial resolutions**



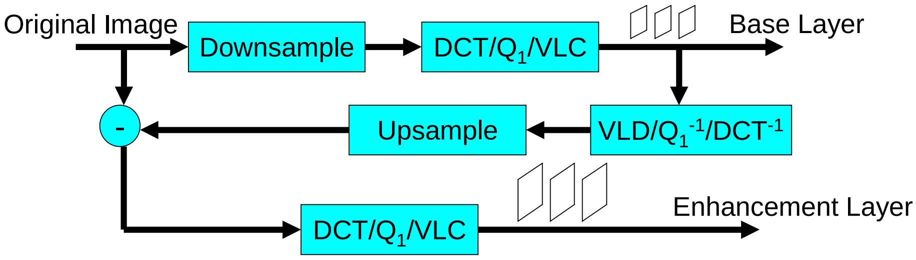
1	2	3	4
1	2	3	5
3	4	5	6
4	5	6	7

Downsampling

1	3
3	5

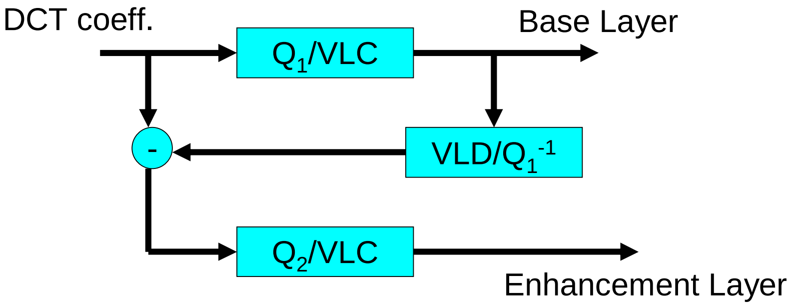
Upsampling

1	0	3	0
0	0	3	0
3	0	5	0
0	0	0	0



SNR Scalability

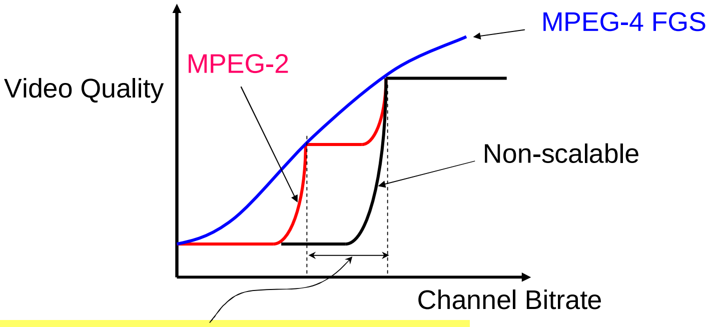
- Code a video into two layers with different quantization accuracies



$Q_1 > Q_2$

Deficiency of MPEG-2 Scalable Coding

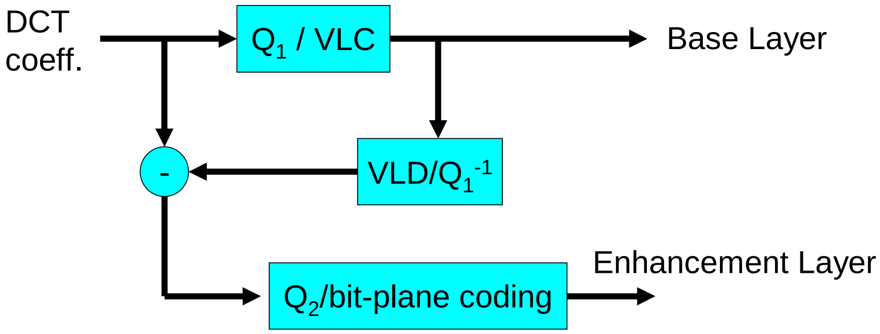
- MPEG-2 only provides two layers
  - **Dramatic change in the video quality as channel bandwidth varies**
- MPEG-4 provides many more layers
  - **Continuous video quality improvement is desirable to maximally utilize current channel bandwidth**



No video quality improvement although the channel bit rate increases

MPEG-4 FGS Layer Structure

- Enhancement layer is equal to the original image minus the reconstructed image from the base layer



DCT coeff.

Q_1 / VLC

Base Layer

-

VLD/Q_1^{-1}

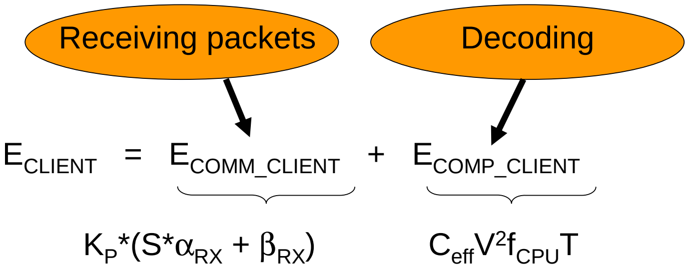
Enhancement Layer

Q_2/bit-plane coding

Energy Consumption in Video Streaming

- There are two sources of energy consumption in wireless video streaming : the communication energy and the computation energy
- Communication energy
  - Transmitting packets (server)
  - Receiving packets (client)
- Computation energy
  - Packetization (server)
  - Decoding bit-streams (client)
- A video streaming system in which a server with infinite energy source and a battery-powered mobile client is considered

Energy Consumption at the Client



Receiving packets

Decoding

$$E_{CLIENT} = \underbrace{E_{COMM\_CLIENT}}_{K_P*(S*\alpha_{RX} + \beta_{RX})} + \underbrace{E_{COMP\_CLIENT}}_{C_{eff}V^2f_{CPU}T}$$

K_p : number of packets
S : packet size
α_{RX}, β_{RX} : regression coefficients

C_{eff} : effective capacitance
V : operating voltage
f_{CPU} : operating frequency
T : streaming time

Energy Waste at the Client

- **Video streaming is a real-time operation**
  - **If the client cannot process all the packets from the server in a given deadline, then the communication energy is wasted with no improvement of video quality**

Ex) Arrived packet count : A
Decoded packet count : M

Video quality = min(M, A)

If A > M, then (A-M) packets become useless, resulting in energy wasted in receiving these packets and ignoring them

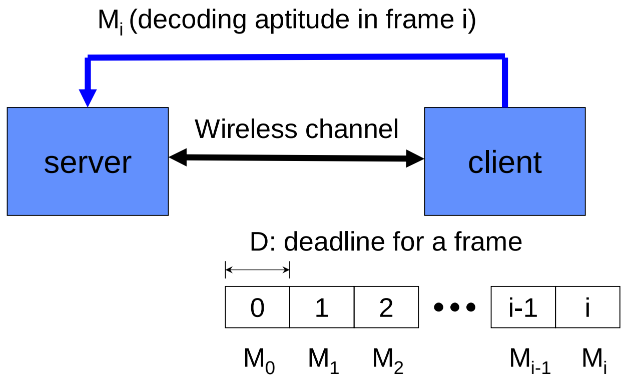
- **For an energy-efficient streaming in which no energy waste occurs, A should be equal to M**

Decoding Aptitude of the Client

- Decoding aptitude (M) of a mobile client
  - The amount of data that can be decoded in a given deadline
  - M is proportional to the CPU frequency of the client
  - M can be changed by dynamic voltage and frequency scaling (DVFS) or dynamic power management (DPM)
- N_i, normalized decoding load at time instance i, is defined as the ratio A_i/M_i
  - A_i : the number of correctly arrived packets at the client
  - M_i : decoding aptitude
- N_i represents the degree of energy waste and should be kept at one for no energy waste
- In order to make N_i one, the server should know M_i

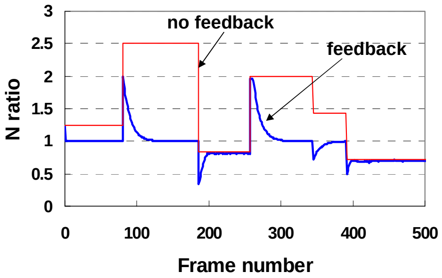
Client-feedback Video Streaming

- The client sends a status packet to the server at regular time intervals
- The server sets the amount of data to be transferred based on the client status, making N_i equal to one



Simulation Results on Apollo Testbed II

- Variations in N_i with different M_i/B ratios
  - M_i : decoding aptitude at instance i
  - B : maximum number of packets the server can send
- M_i trace : 0.8B, 0.4B, 1.2B, 0.5B, 0.7B, 1.4B
- Channel model : Gilbert-Elliot model with bit error rate (BER) of 1e-5 and 1e-4 for good and bad state, respectively

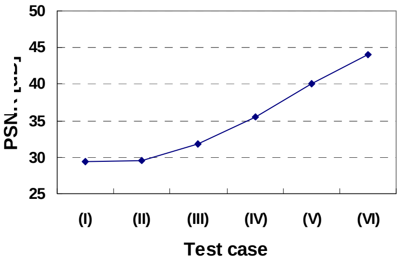


	Energy waste	
	No FB	FB
0.8B	18.74%	0.21%
0.4B	57.35%	2.57%
1.2B	0%	0%
0.5B	48.49%	6.27%
0.7B	28.69%	0%
1.4B	0%	0%

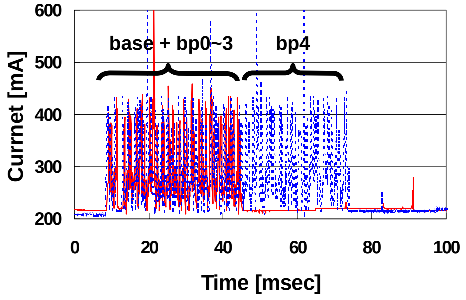
Experimental Setup

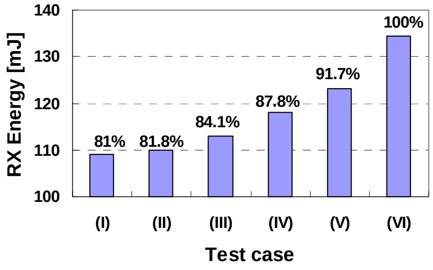
- Generated MPEG-4 FGS bit-streams using a QCIF test video
  - A base + FGS with five bit planes(bp0~4)
  - 256-byte packet size
- Six test cases
  - (I) base layer only
  - (II) base + bp0
  - (III) base + bp0 + bp1
  - (IV) base + bp0 + bp1 + bp2
  - (V) base + bp0 + bp1 + bp2 + bp3
  - (VI) base + bp0 + bp1 + bp2 + bp3 + bp4
- Peak signal to noise ratio (PSNR) increases as more bit-planes are decoded

	Size(byte)	Packet number
Base	76	1
FGS Header	9	1
bp0	18	1
bp1	278	2
bp2	1007	4
bp3	2022	8
bp4	3358	14

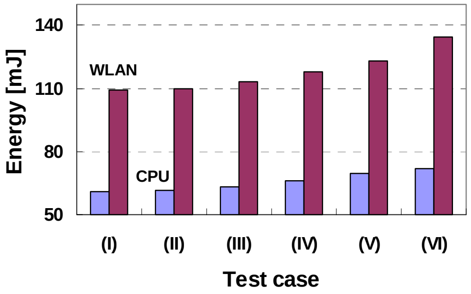


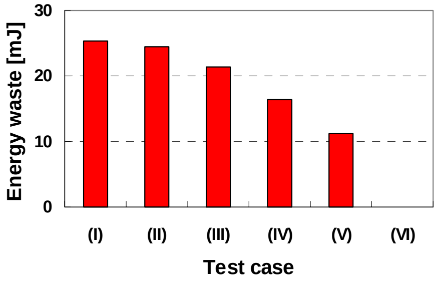
Energy of Wireless LAN Card for Receiving Packets





Energy Consumptions of the CPU and WLAN

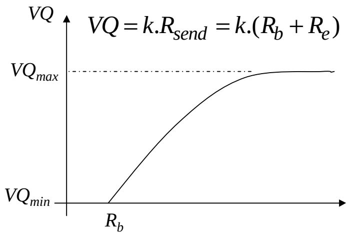




Energy-Aware Wireless Video Streaming in Adhoc Networks

- **Given are a minimum throughput and a maximum bit-error-rate**
- **Server's policy is to adopt**
  - **Operating frequency of the CPU, f^S**
  - **Transmit power, P_{amp}**
  - **Set of modulation levels of the OFDM subcarriers, b_i**
- **Server's cost function is**
  - **the total energy consumption of the client-server system in each frame**
- **Client's policy is to adopt the**
  - **Operating frequency of CPU, f^C**
  - **Truncation length of OFDM subcarriers, TL_i**
- **Client's cost function is**
  - **the remaining lifetime difference between server and client**

Fine Granularity Scalability feature of MPEG4

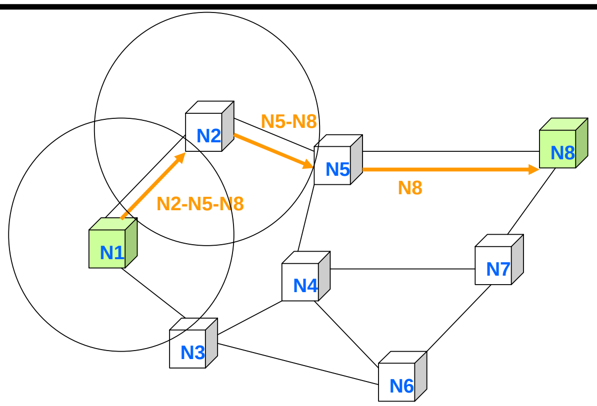


- **The Stackelberg game theory is used to reduce the redundant energy consumption in a wireless video streaming system**
- **A maximum of 20% increase in the system lifetime is achieved. Moreover, average lifetime increases by 15%**
- **It is easy to transfer to the ADS bitsyX board**
  - **Needs protocol/Application modification**

Energy-Aware Routing in MANETs

- **Power is one of the key design criteria in Wireless Adhoc Networks**
- **Network can become disconnected if some nodes die out due to lack of energy**
- **A design goal is to maximize the (useful) network lifetime by minimizing the variance of the remaining battery lifetime of the nodes in the network**
- **Our focus here is on on-demand (reactive) Multicast routing protocols**
- **Routing protocol ought to be responsive to the dynamics of the network (node density and mobility, energy discharge rates and traffic load)**

Dynamic Source Routing in MANET 101



- Assume fixed transmit power and fixed energy-conserving strategy in each node
- Route discovery is done by flooding the network with Route Requests
- Nodes promiscuously listen to control messages flowing through the network; Caching techniques improve performance considerably

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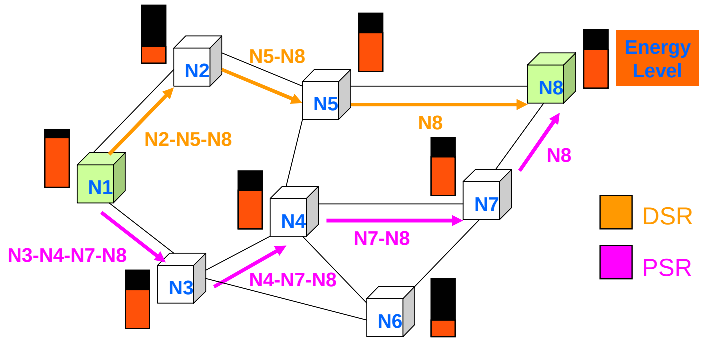
Power-aware Source Routing (PSR)



- Minimize sum of the energy cost of the links along the routing path
- Link cost is proportional to the inverse of the remaining battery capacity (residual energy) of the transmitting node

PSR: Route Discovery

- Similar to DSR, but with the following differences:
  - An intermediate node passes on the first RREQ and all subsequent lower-cost RREQ's until a local timer expires
  - Destination starts a timer after receiving the first RREQ and replies back only after that timer expires
- Control packet overhead for PSR is higher than that of DSR

PSR: Route Maintenance

- Similar to DSR, but with the following differences :
  - Path cost changes with time, and hence, cache entries of a node should not remain valid for a "long" period of time (aged cache entries should be purged from the cache tables of all nodes along the path)
  - Each node in the path monitors the decrease in its residual energy from the time of route discovery; When this link cost increase goes beyond a threshold level, the node sends a route error back to the source as if the route was rendered invalid
  - Invalidated routes are added to a victim buffer
- PSR results in a higher degree of energy balancing in the network

PSR: Exact Cost Function

$$\min_{\pi} \; C(\pi,t) = \sum_{i \in \pi} C_i(t)$$

$$\text{where } \; C_i(t) = \rho_i \cdot \left(\frac{F_i}{E_{r,i}(t)} \right)^{\alpha}$$

ρ_i: transmit power level of node i

F_i : full-charge battery capacity of node i

$E_{r,i}(t)$: remaining battery capacity of node i at time t

α: a positive weighting factor

- A cost is associated with every node on the path
- This cost is inversely proportional to the normalized residual energy of the node
- The cost function is graded, i.e., nodes with very low battery capacity dominate the total cost of the path

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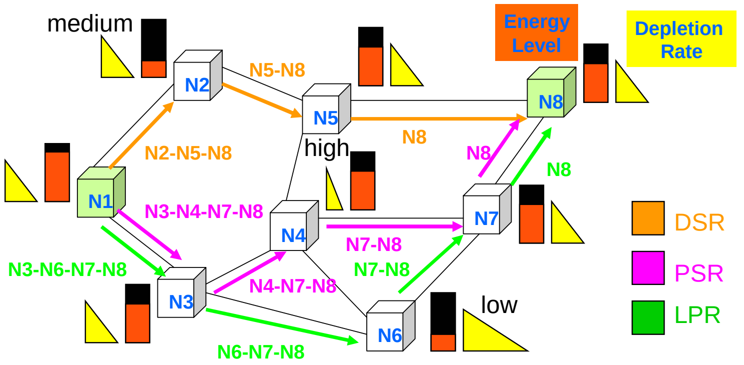
Lifetime Prediction Routing (LPR)



- Maximize the minimum link cost along routing path
- Link cost is remaining lifetime of transmitting node
- Node lifetime is equal to the remaining battery capacity divided by the energy depletion rate

LPR: Exact Cost Function

$$\max_{\pi} T_{\pi}(t) = \min_{i \in \pi}(T_i(t))$$

$T_{\pi}(t)$: lifetime of path π
$T_i(t)$: predicted lifetime of node i in path π

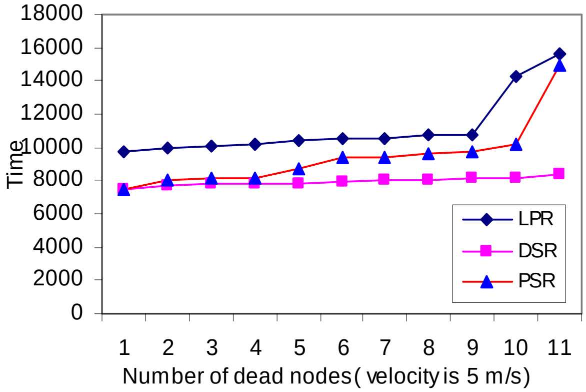
$$T_i(t) = \frac{E_{r,i}(t)}{R_i(t)}$$

- **$E_{r,i}(t)$: remaining energy of node i at time t**
- **$R_k(t)$: history-based rate of energy depletion of current node at time t**
- **N: length of the history used for calculating the simple moving average**

Simulation Setup

- **20 nodes in 1000 x 1000 area with random way-point mobility**
- **380 UDP connections which are randomly initiated between nodes at simulation time**
- **Key parameters of study are the network lifetime and RMS of energy consumption (Erms) in the network**
  - **Effect of mobility**
  - **Effect of radio transmission range**

Network Lifetime



- **LPR > PSR > DSR in terms of network lifetime**
- **Lifetime prediction is an effective technique to increase the network lifetime**

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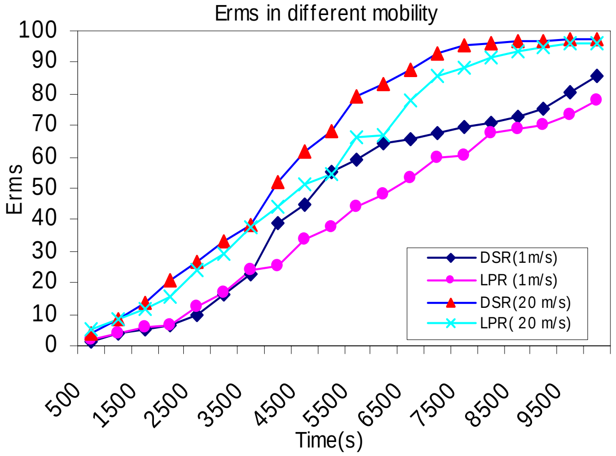
Effect of Mobility on Evaluation of Erms



- **LPR is better than DSR in terms of energy variance**

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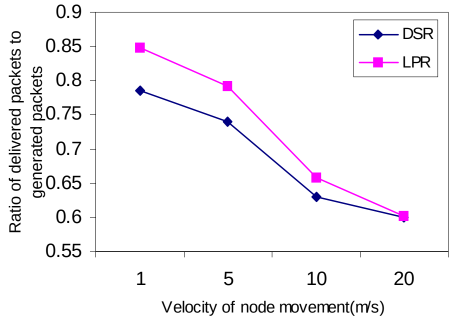
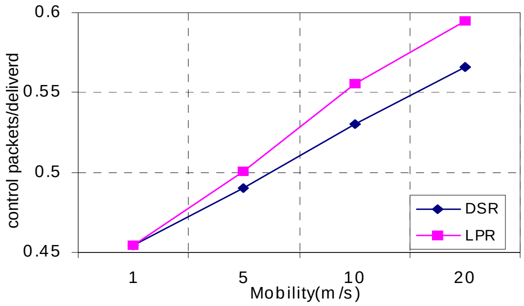
Effect of Mobility on Packet Delivery Ratio



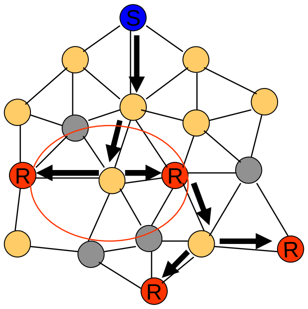
- As velocity of node movement increases, ratio of packets delivered to packets generated for LPR goes down
- At higher velocities of node movement, LPR does not exhibit a significant gain over DSR

Effect of Mobility on Control to Data Packet Ratio



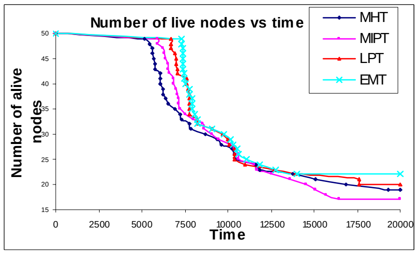
- Ratio of control packets to delivered packets in the network increases as velocity of node movement goes up for LPR
- Overhead of control packets is less than 6%

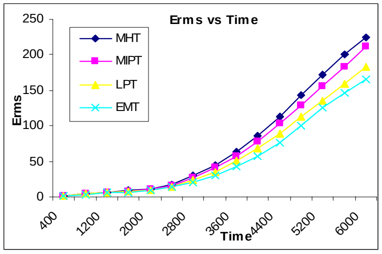
Energy-aware On-demand Multicast Routing in Wireless Adhoc Networks



- Find a minimum-cost tree, which connects the source node S to all receivers in set R
- Maximize the network lifetime by minimizing the variance of the remaining battery lifetime of the nodes in the network
- There are two distinct methods to send out the packets from a multi-fanout node:
  - Multiple unicast
  - Single broadcast (more energy efficient)
- Must account for the "neighbor cost"

$$C(T,t)=\sum_{i\in T}\left\{\rho_i\cdot\left(\frac{F_i}{R_i(t)}\right)^{\alpha}+\left(if\ \deg(i)\ge 2\quad then \sum_{j\in neigh(i)\wedge j\notin T}\left(\frac{F_j}{R_j(t)}\right)^{\alpha}\ else\ 0\right)\right\}$$





Summary

- Energy consumption of an MPEG-2 decoder can be reduced by employing an application –aware DVFS strategy by as much as 20%
- By using a client-feedback method for the MPEG-4 streamer, about 20% reduction in the communication energy is achieved, which is up to 40% of the CPU energy
- Power-aware Routing protocols attempt to improve the network lifetime and balance both the remaining energy and energy depletion rate of the nodes in a MANET with low control overhead
- Performance of these protocols varies based on: Mobility, Radio transmission range, and Accuracy of lifetime prediction