System Utility Functions for Adaptive/Reconfigurable MANETs

Gustavo de Veciana
gustavo@ece.utexas.edu

Motivation:
Reconfiguration/Adaptation of MANETs

- Potential to significantly enhance usefulness of MANETs
- Difficulty in designing universal protocols that are good over all deployment scenarios/environments
- Incorporating context and contingencies (mission-specific objectives) in network design
  - How much effort should one expend in maintaining connectivity?
  - How should one prioritize and exploit structured workloads?

Specifying System Objectives

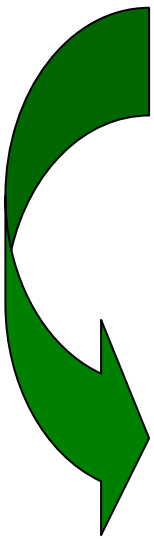
- Action oriented
  - Specification of rules, e.g., priorities
- Goal oriented
  - Specification of goals, e.g., quality of service
- Utility based
  - Specification of tradeoffs
  - Higher level notion of system objectives

Dual Role for System Utility Function

- Drives Adaptation/Reconfiguration Process
  - Implicitly capture network designer's intent, i.e., desirable operation, tradeoffs among network/application concerns for a range of operational scenarios
- Test and Evaluation Metric
  - Objective metric by which to test & evaluate various adaptation/reconfiguration strategies

Tradeoffs: Perspectives and Examples

Coupled together

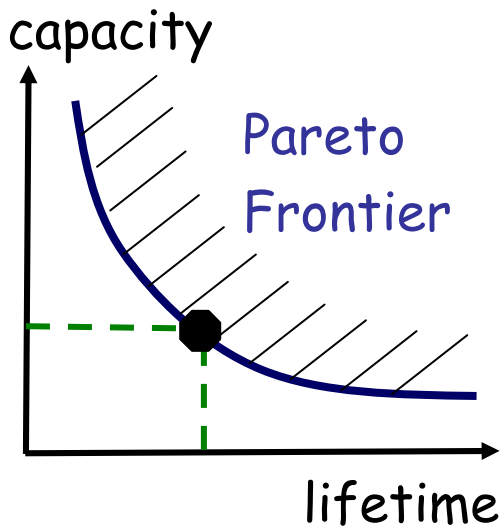


e.g., connectivity necessary to support tasks

Network Perspective, e.g.,
- Connectivity
  - How much effort to expend maintaining connectivity?
- Network/node lifetime
  - How much energy to expend delivering high capacity?
- Security

Application Perspective, e.g.,
- Utility derived by tasks
  - Tradeoffs among quality of service (QoS) delivered to diverse tasks

Selecting Tradeoffs



Tactical Missions - Typical Applications

File transfers: e.g., sharing files with maps, slides

- Transport: Reliable multicast
- QoS: overall transfer delay

Situational Awareness: e.g.,persistent regular updates keep set of nodes aware of location and state of other nodes/users

- Transport: likely unreliable multicast
- QoS: late/or out of order packets worthless

Voice: likely to be of the **push-to-talk** type among set of users

- Transport: likely to be unreliable multicast
- QoS: sensitive to packet loss, delay and jitter

Tactical Missions - Typical Applications

Video: real-time packet video

- Transport: unreliable multicast or RTP/UDP
- QoS: sensitive to packet loss, delay

Collaboration/whiteboard: maintain common state among set of nodes,

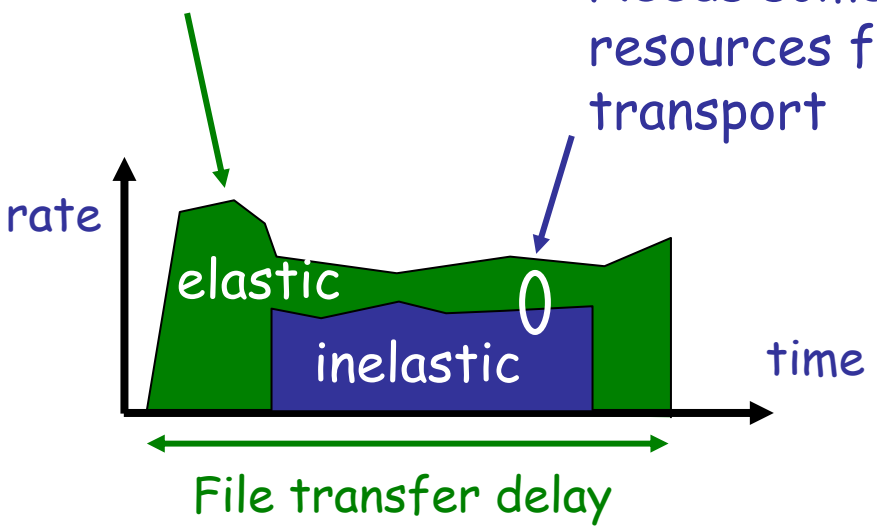
- similar to SA but more bursty, might further involve file transfers, voice, video (separate tasks)
- Transport: reliable multicast
- QoS: sensitive to packet loss/delays

In summary,

- Majority of tasks involve a set of nodes/users.
- A task's resource requirements highly dependent on set of users involved and evolving network topology
- Precise a priori evaluation of relative importance challenging

Rough Application Taxonomy [1]

- Elastic:
  - E.g., file transfer
  - QoS: average transfer rate (delay) experienced
  - Can adapt transmission to congestion
- Inelastic
  - e.g., SA, voice/video
  - QoS: fraction of useful packets received in a timely fashion
  - Needs some minimal resources for adequate transport



[1]Shenker, Fundamental design issues for the future Internet, IEEE JSAC, 1995

Task workload for a MANET

- `Independent' task workload -- idealization
  - Offered work load independent of network topology and QoS offered to other tasks
  - Decouple network and offered workload

$$W = \{(a_i, R_i, s_i, u_i, w_i) | i = 1, 2, \ldots, m\}$$

Application type

Receiver set

Start time

weight

Utility function

Task Utility Based on QoS

- QoS for Task i at time t --receiver oriented

$$\vec{q}_i(t) = (q_i(t,r)|r \in R_i)$$

- Utility derived by Task i at time t

$$u_i(\vec{q}_i(t))$$

Normalized not to exceed 1

- Set of tasks which are active at time t

$$A_t = \{i|s_i \leq t \leq f_i, i = 1, \ldots, m\}$$

Finish time for task i

Normalized Current and Overall Utility

- Normalized weighted current utility
  - Convention: set to 1 when no tasks are active

Adaptation/reconfiguration policy *p*

$$U_t^n(W,p) = \frac{\sum_{i \in A_t} w_i u_i(\vec{q}_i(t))}{\sum_{i \in A_t} w_i}$$

Depends on *p*

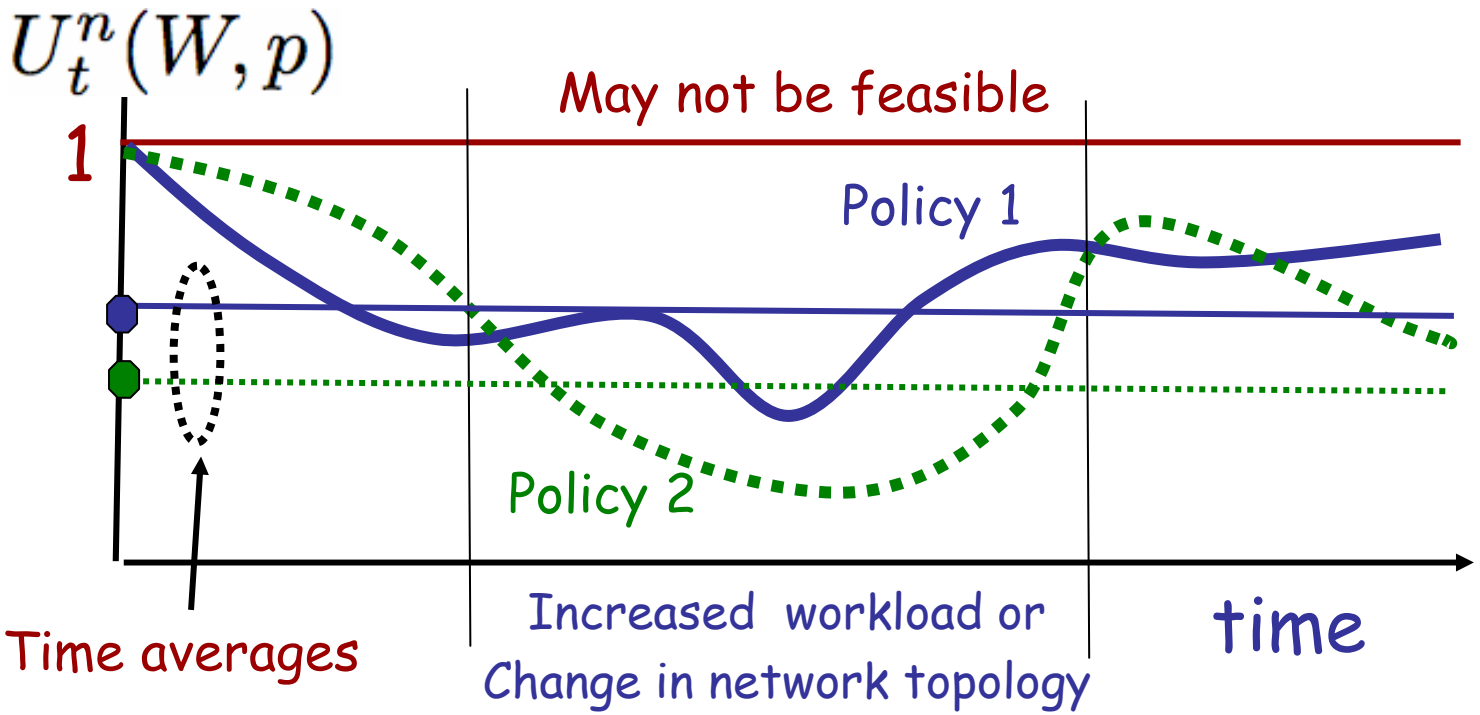
- Overall system utility

Duration of operation

$$U^n(W,p) = \frac{1}{t^*} \sum_{t=1}^{t^*} U_t^n(W,p)$$

Time average

Current and Overall System Utilities



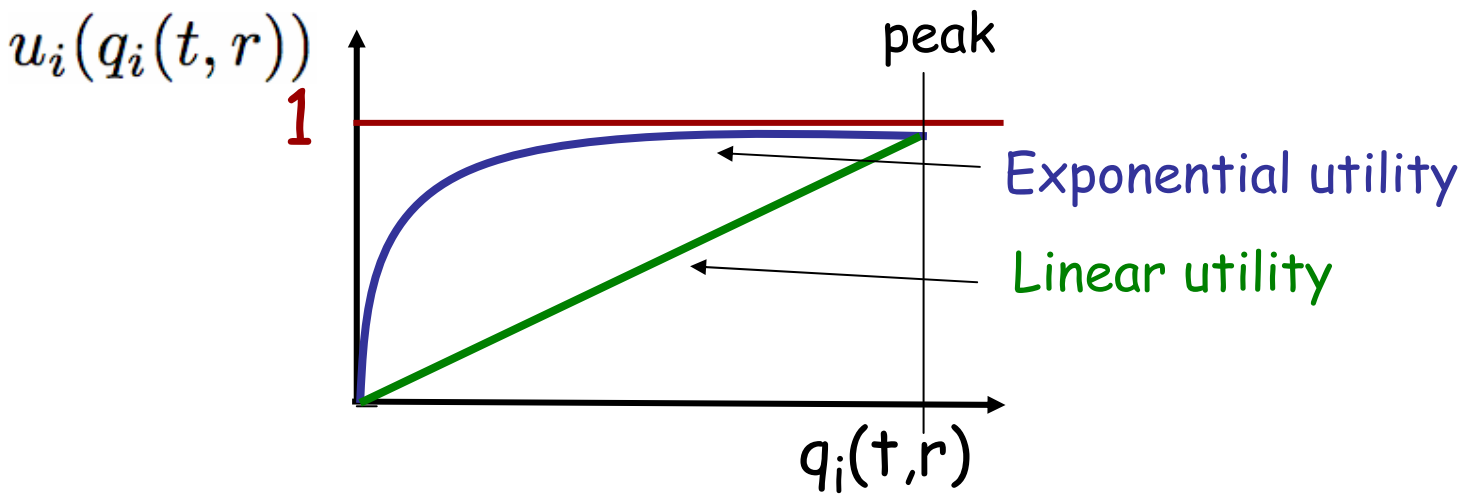
How well are we doing relative to best weighted application-level utility?

Application-level Utility Functions:
Elastic Applications -- Single receiver

- QoS for elastic task i on time slot t

$$q_i(t,r) = \frac{\text{bits succesfully received by } r \text{ on slot } t}{\Delta}$$

- Utility derived by task i
  - Concave function of current throughput, e.g, [2]



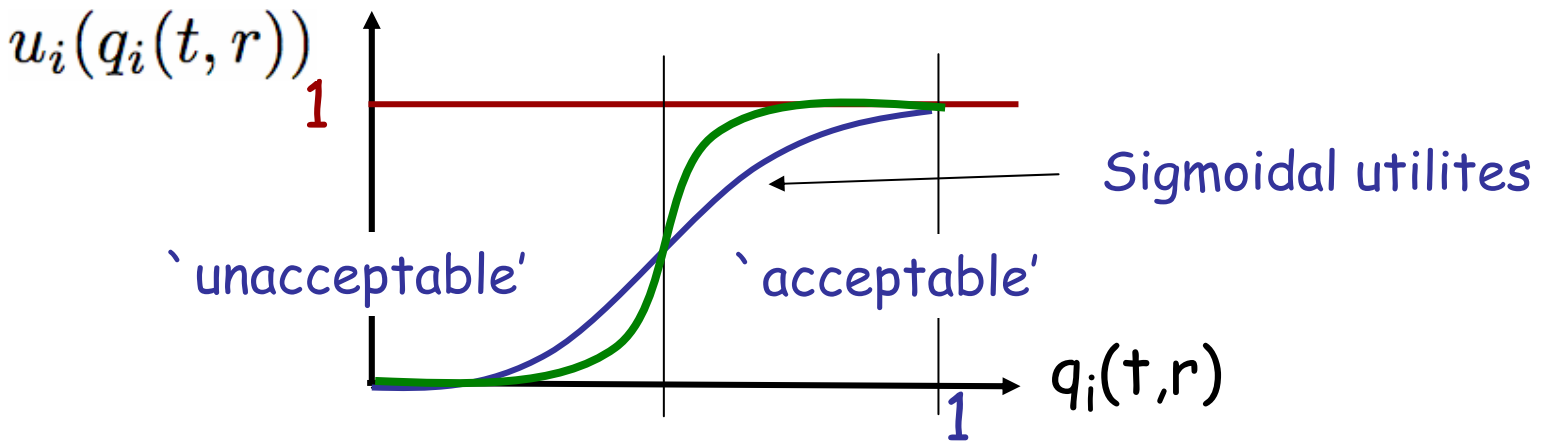
[2] Jiang et al., A subjective survey of user experience for data apps. in future cellular wireless networks, Proc of SAINT, 2001

Application-level Utility Functions:
Inelastic Applications -- Single receiver

- QoS for inelastic Task i on time slot t

$$q_i(t,r) = \text{fraction of 'useful' packets recieved by } r \text{ on slot } t$$

- Utility derived by Task i
  - Acceptability = `threshold' on QoS, e.g., [3]



[3] Ghinea et al, QoS impact on user perception and udnerstanding of multimedia video clips, ACM Multimedia 1998

Application-level Utility Functions:
Multi-point sessions

- Recall, majority of tactical applications involve sets of nodes/users

- Utility for tasks involving sets of users
  - composite of receiver-oriented utilities
    - Arithmetic average
    - Harmonic average
    - Minimum across receivers, etc.,

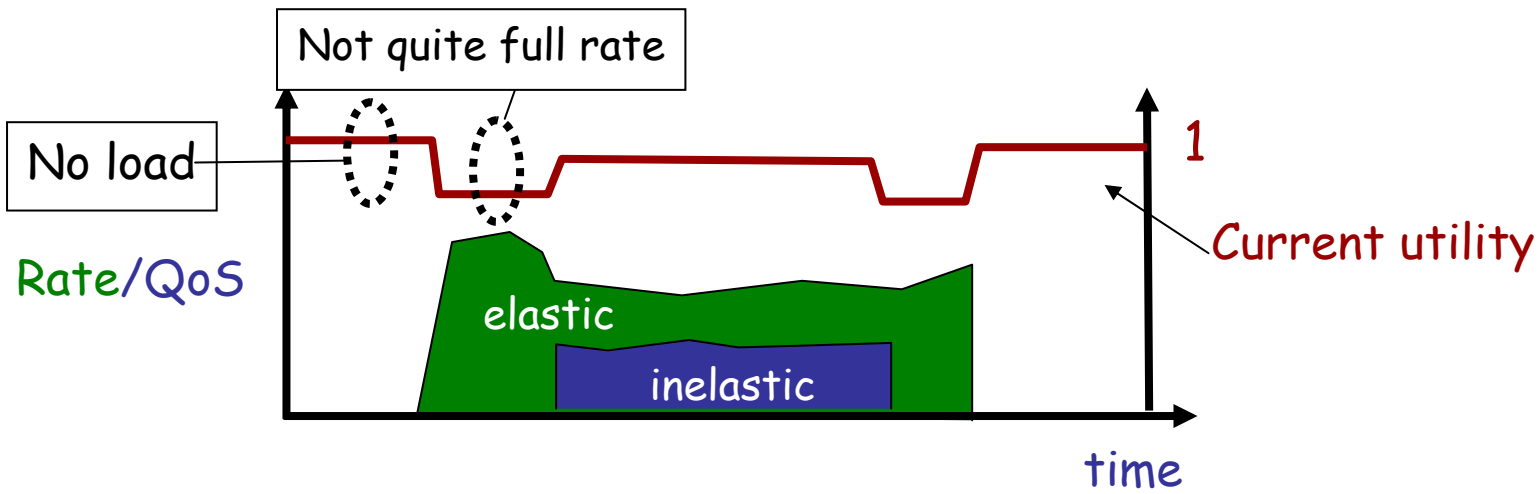
Specifying Overall System Utility

- Application-level utilities capture sensitivity of tasks/users to QoS
- Relative importance of tasks captured through task weights
- Together, these provide network designer a rich palate to specify tradeoffs among tasks

Some Desirable Properties:

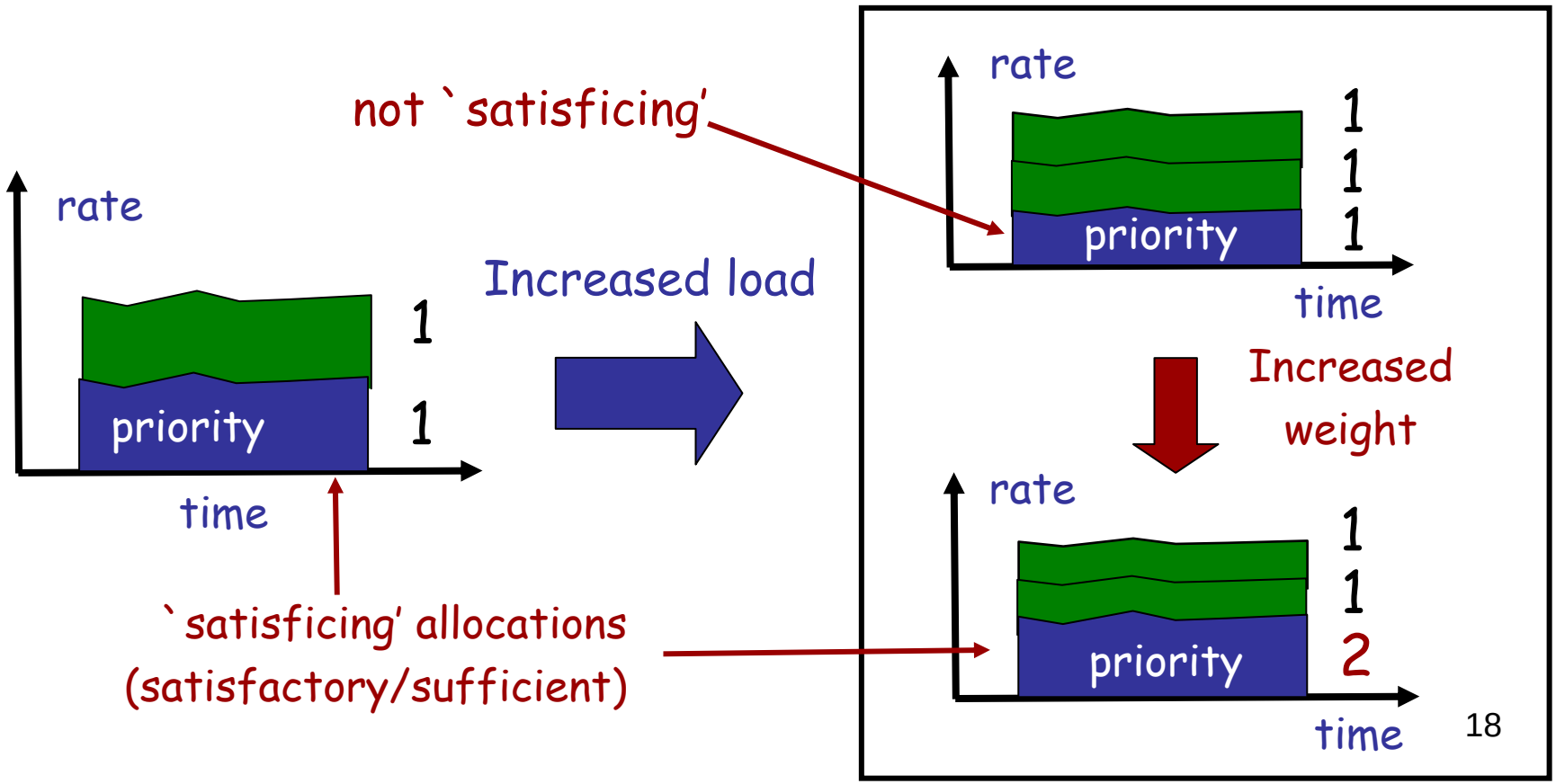
Dynamic Loads of Elastic and Inelastic Applications

- Current throughput of elastic application is traded off against QoS for inelastic applications
- Incentive to expedite elastic tasks
  - Because utility of idle network is 1



Anomalies and Difficulties

- Weights achieve only **relative** prioritization
  - I.e., allocated resources depend on load scenario



Challenges in Selecting System Utility

- Robustness: range of scenarios covered by given choices of utilities/weights
- Mission-dependent / contextual character of such specifications
  - Changing importance of tasks as a mission unfolds
- Need to capture additional operational requirements
- Incorporating tradeoffs among application utility and energy, safety, security etc..

Operational Constraints

- Supplement Application-level System utility
  - Capture network perspectives, connectivity, energy etc.
- Explicitly introduce actions/goals as constraints on operation,
  - Maintain minimal connectivity requirement
  - Specify operational requirement on network lifetime
  - Maintain strict rather than relative prioritization among tasks

Summary - Research Challenges

- Objective is to show substantial benefits through selection of a satisfactory overall mission-oriented utility and control-based reconfiguration/adaptation of MANETs.

- Tools for overall system utility design based on experience and contextual information likely to be required to help tune network to range of possible contexts/contingencies.