Emergency Communications in Public Telecommunications Networks

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First of All, Thanks

- Students
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- Researchers
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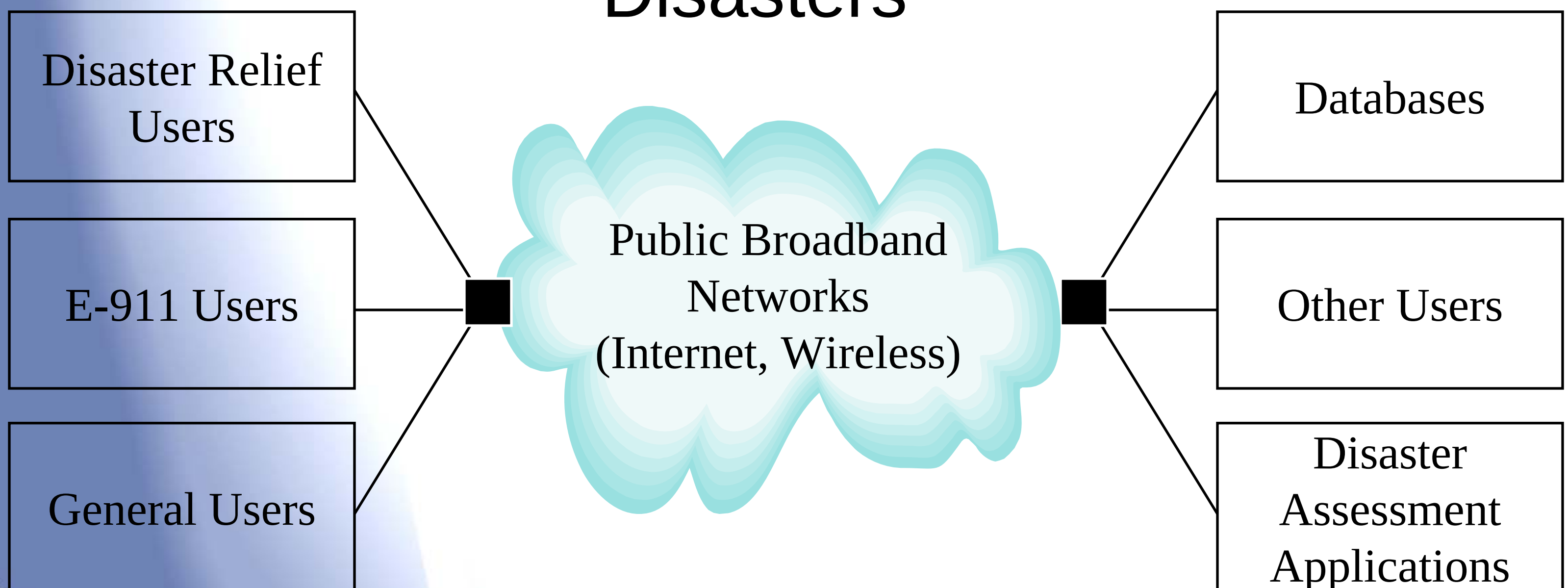
- National Science Foundation

Disaster Communications

Timely Access to Multimedia Communications Is Needed In Response to Natural and Man-Made Disasters



Stressed Networks

- Public Networks Become Heavily Loaded
  - From High and Low Priority Users
- Need: More Available Capacity for Priority Use
  - New Capacity Could be Installed in a Few Hours or Days
  - If There Were an “Emergency Lane” for Priority Traffic, High Priority Users Could Communicate on Public Networks
- Disaster Recovery is Highly Dynamic
  - Disasters Occur Suddenly
  - Recovery Occurs in Phases - Search and Rescue, Medical Relief, Economic Relief, Rebuilding

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Stressed Networks

- Public Network Resource Availability during Disasters is Highly Problematic
  - Demand can be up to five times normal levels.
  - "An inability to place or complete a call on the network due to network overload and congestion have plagued emergency response."
  - Radio systems are unused on a day-to-day basis; inadequate when a major event occurs.
  - For Oklahoma City Bombing 1995),
    - Out-of-town media (lower priority users) called 9-1-1 center and demanded to stay on the line until they could get information.
    - Response workers had trouble making calls to find out assignments.
    - Users did not hang up once lines were obtained.

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Types of Communication

- Connection-oriented
  - Prioritize who gets to set up and continue connections
  - Examples
    - Public Switched Telephone Network
    - Cellular Wireless
    - Connection-oriented packet networks

Types of Communication

- Packet Switched
  - Prioritize how packets are handled.
  - Emergency users need not have better quality of service (QoS) at the packet level.
  - But what do emergency users really need?
  - Examples
    - General Internet
    - Access networks (Cable modem, DSL)
    - Wireless cellular (3G, 4G)
    - Wireless random access (802.11)

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General Principles

- Public users are also important.
  - Their activities may also be urgent.
  - And even if not, calm attitudes of the public are important to maintain after disasters.
- Avoid *unnecessarily good* service.
  - Emergency users don't need 100% acceptance, zero delay, or the fastest packet delivery possible.
- The real requirements of emergency users are more qualitative.
  - Availability – Resources are available when needed.
  - Dependability – Intended activities can be completed successfully.

Connection-Oriented Communication

- Every user is associated with a “call” or a “session”.
  - Resources are likely assigned to that call in some way.
    - Possibly shared
  - If all resources are currently being used, the call by default is blocked.
- What are ways to provide emergency priorities in this type of environment?

Connection-Oriented Communication

- Resource Conservation
  - Keep some capacity available only to priority connections
- Preemption
  - Interrupt lower priority flows when higher priority ones need capacity.
- Call queueing
  - Use time to the benefit of higher priority flows.
  - One approach: If higher priority flows are first blocked, allow them to wait in a queue and get the first capacity that becomes available.
  - Another approach: Preempt lower priority flows, but put them "on hold" (in a queue), instead of discontinuing them.

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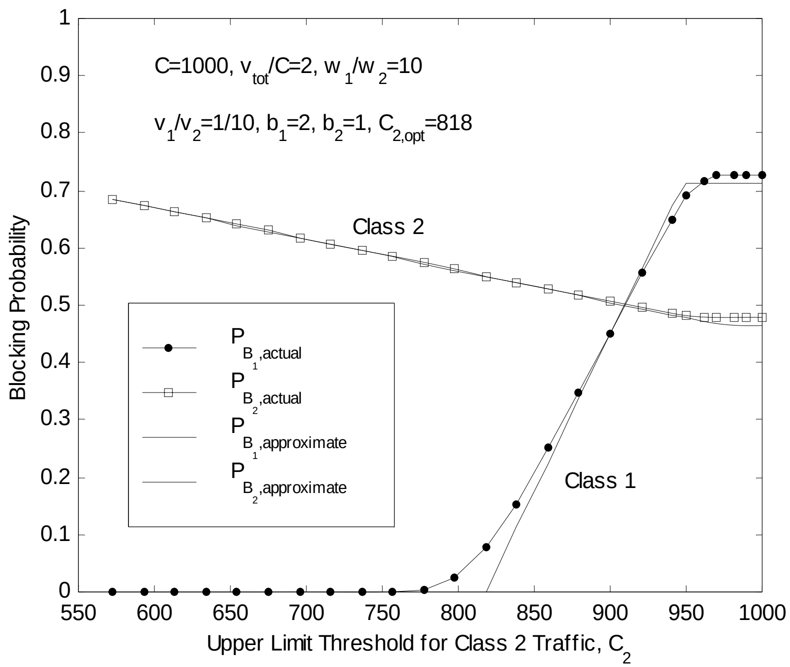
Resource Conservation

- Resources are protected for use only by emergency traffic.
- A balance is struck between emergency and public demands, based on the blocking probability for each.
- Can be analyzed by multi-dimensional Markov chains.
  - Since call arrivals and call service times are commonly exponentially distributed. Results are commonly in product forms.
- What is the main problem with this type of approach?



Preemption

- Preemption has several benefits.
  - Good resource utilization.
  - Immediate access for emergency calls.
- But preemption can be very harsh.
  - Existing public calls are interrupted and dropped.
  - Some governments, like the U.S. government, are not allowed to use preemption.
- What are ways preemption could be “softened”?

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Preemption

- Softer approaches
  - Lower QoS instead of ending a call.
  - Queue preempted calls.
    - Allow them to return later.
    - Maybe only let them be preempted once.
  - Do not always allow preemption.
    - Depending on how many emergency calls are already present.
  - Give warnings before preempting.

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Preemption

- Research
  - Applied to wireless cellular networks.
    - So handoffs must be considered.
  - Queue preempted calls.

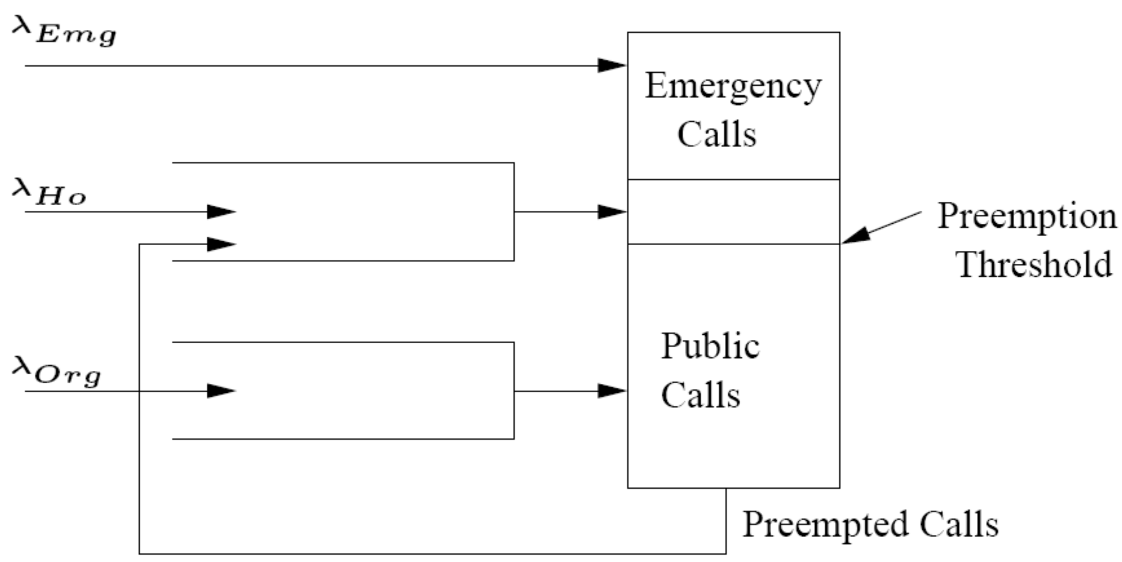

Fig. 1. Combined preemption and queueing scheme

Preemption

- Model using Markov chains
  - Preemptions do not allow product form solutions.
  - Set thresholds when preemption is allowed and not allowed.

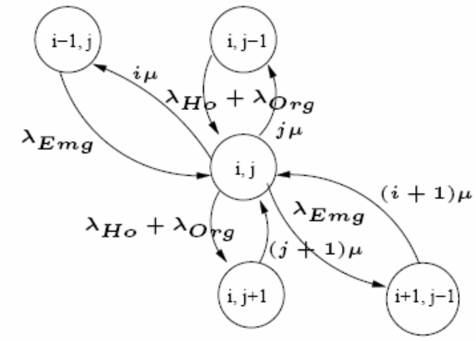

Fig. 2. The typical state change when channels are non-full

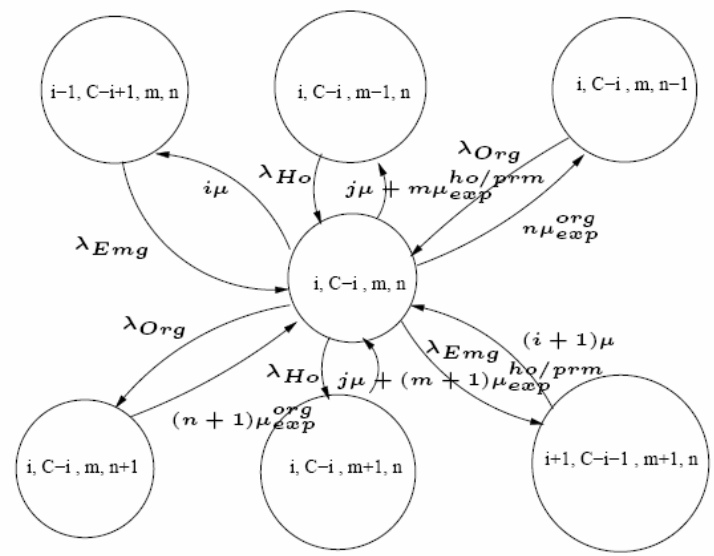

Fig. 3. The typical state change when channels are full

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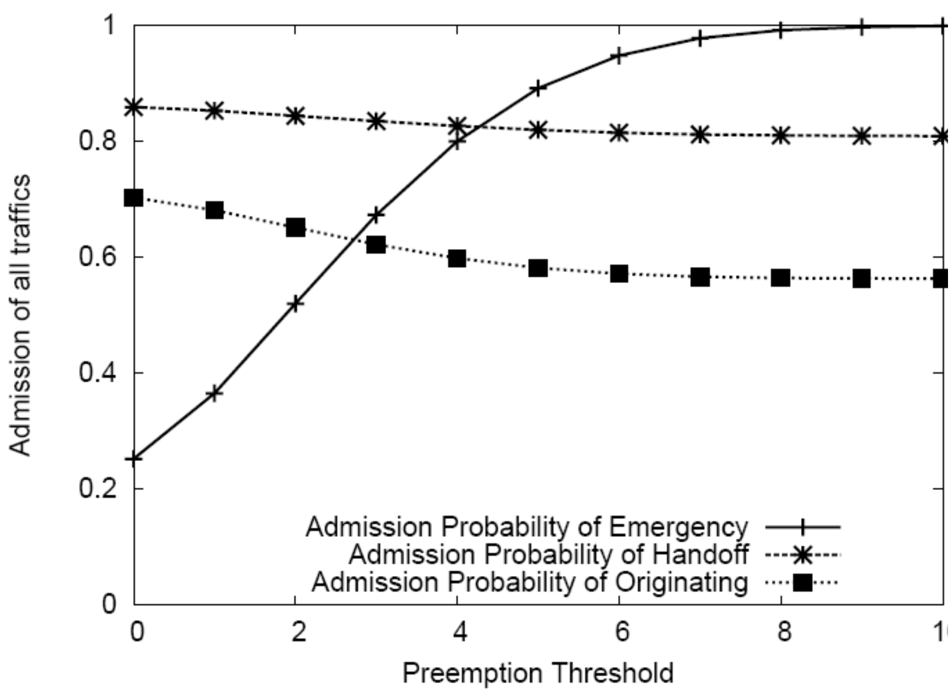
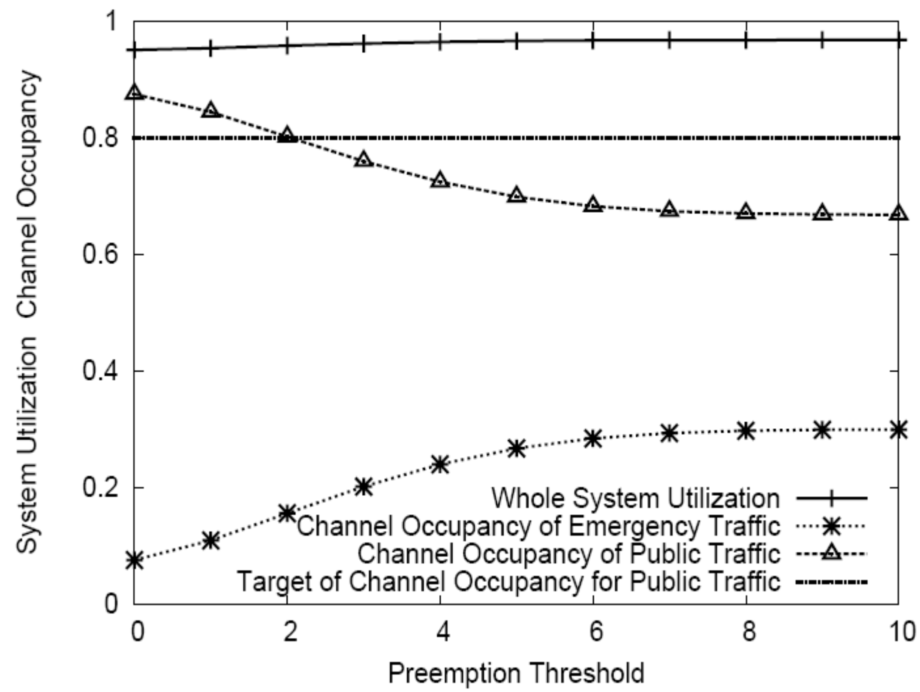
Preemption


Admission of all traffics
Preemption Threshold
Admission Probability of Emergency
Admission Probability of Handoff
Admission Probability of Originating


System Utilization Channel Occupancy
Preemption Threshold
Whole System Utilization
Channel Occupancy of Emergency Traffic
Channel Occupancy of Public Traffic
Target of Channel Occupancy for Public Traffic

Call Queueing

- How does this compare with preemption?
  - Just as effective in resource utilization.
- Problem
  - Waiting time in queues before getting to start calls.
  - Expiration – Users that are waiting in queues give up on their calls.
    - We model this with exponential random variables.

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Existing Systems

- Government Emergency Telephone Service (GETS)
  - PSTN
  - A very select group of emergency managers can use this through special access codes.
  - If no channel is available, the call is queued and given the first available channel.
- Call queueing approach
  - Emergency calls that are blocked are then (1) put into a queue, and (2) given first priority when a channel becomes available.
  - No preemption or channel reservations.

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Existing Systems

- Wireless Priority Services
  - Became a high priority after September 11, 2001.
    - Extension of the U.S. wireline GETS system that had been around for many years.
    - Used the same call queuing approach.
- Only available from GSM providers
  - Only GSM has priority call identifiers.

FCC Order

- There is concern by the general public that emergency users could use too much capacity.
  - Even though access to WPS is highly restricted, only to high level emergency managers.
  - The general public is not always happy or trusting of emergency organizations (e.g., FEMA in New Orleans)
- So, the FCC issued the following requirement in its Report and Order for WPS:
  - “Insure that at all times a reasonable amount of CMRS (Commercial Mobile Radio Service) spectrum is made available for public use.”

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Nyquetek Report

- Nyquetek Inc., ”Wireless Priority Service for National Security/Emergency Preparedness: Algorithms for Public Use Reservation and Network Performance,” August 30, 2002.
  - It’s recommendations are currently implemented.
- Extensive study in two respects
  - Careful analysis of typical cell loads during emergency situations.
  - Simulation of various approaches to scheduling emergency calls out of the queue.
    - Also queueing calls from the general public.

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Nyquetek Report

- Recommendation
  - Schedule ¼ between emergency and public calls coming out of the queues.
    - Waiting emergency calls are not give absolute top priority.
  - This was seen as striking a good balance between queueing delay and utilization for public calls.
    - A 1/6 schedule, for example, would give 83% to public calls, but also would have 5 public calls starting getting served before the next emergency call.
  - Some adaptations were given for small cells.
- Key targets
  - At least 90% acceptance of emergency calls.
  - Protection so public traffic has ≥ 75% of cell capacity.
  - Keep queueing delays reasonable.

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Benefits of Our Approach over the Nyquetek Approach

- Analytical Solution instead of Simulation
  - Allows for ease of adaptation to new network conditions
    - All cells will not have same demands or balance of demands, especially those close to the disaster area
    - Demands can change
    - So, scheduling parameters can be recomputed using the model
      - Instead of on-demand simulation runs
- Self-Expiration
  - Impatience time is modeled as an exponential random variable.
    - Nyquetek used a fixed call clearing time.

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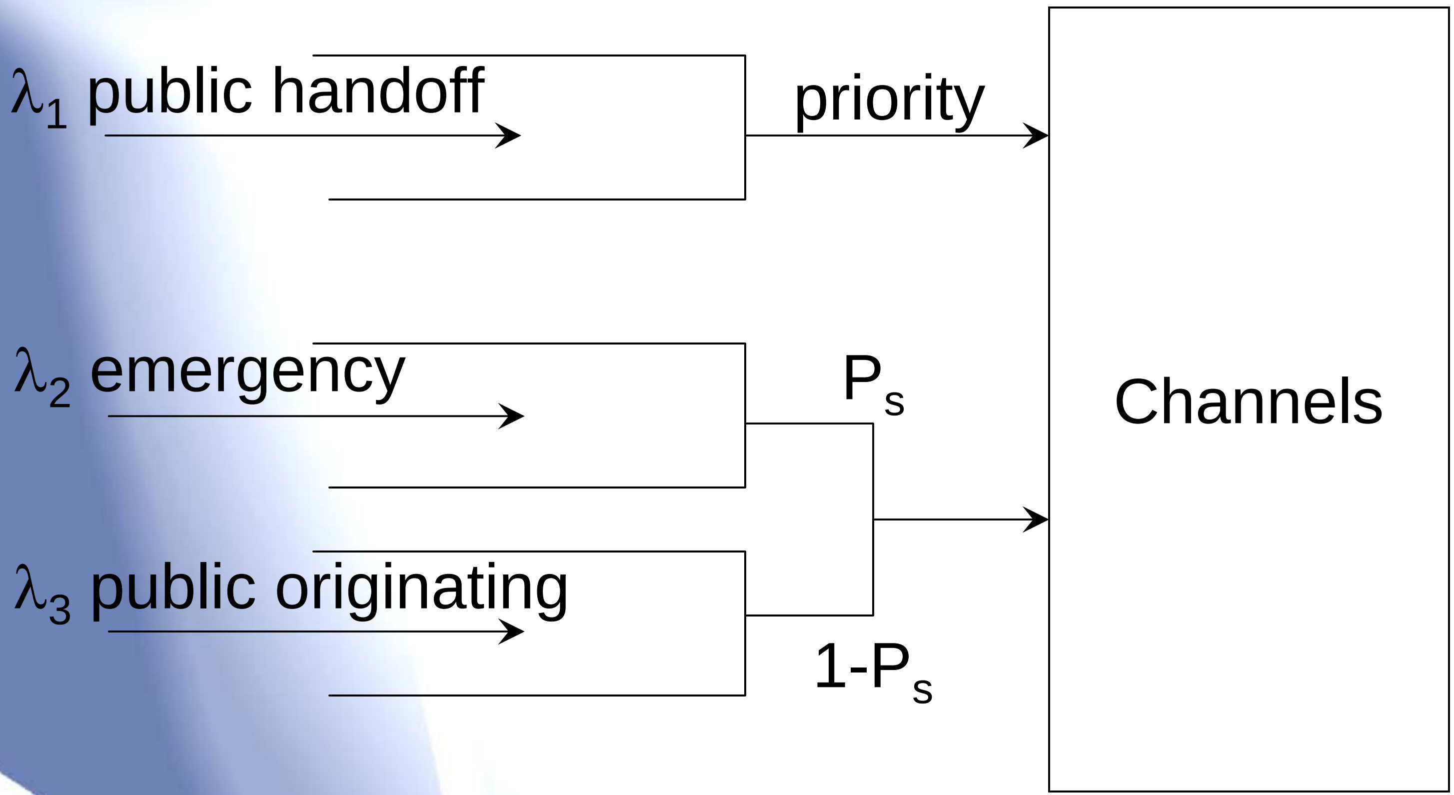
Benefits of Our Approach over the Nyquetek Approach

- Handoffs
  - Many approaches, like the Nyquetek study, use guard channels
    - Which leaves a certain amount of channels unused.
  - But since call queueing is used, we can use it to our advantage.
    - Allow all channels to be used; queue blocked requests for handoffs also.
    - Then use priority queueing for handoff calls.

Probabilistic Scheduling



Markov Model

Performance Parameters

- We have derived all of the important parameters.
  - Blocking probability
  - Expiration probability
  - System utilization and channel occupancy
  - Average time waiting in queue

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Algorithm for Finding the Scheduling Weight Parameter P_s

- Scheduling is based on emergency call admission and public capacity utilization.
  - We could also consider queueing delay, but did not here.
- Depends on how the arrival rate of emergency calls (λ_2) compares with a threshold λ_{thr}.

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Comments

- There are three design constraints
  - Threshold for emergency demand.
  - Target utilization by public calls.
  - Target emergency admission probability.
  - The first two need to total less than or equal to 100%.
- During normal operations (low demand), set P_s=1.
  - There would rarely be calls in both the public and emergency queues.

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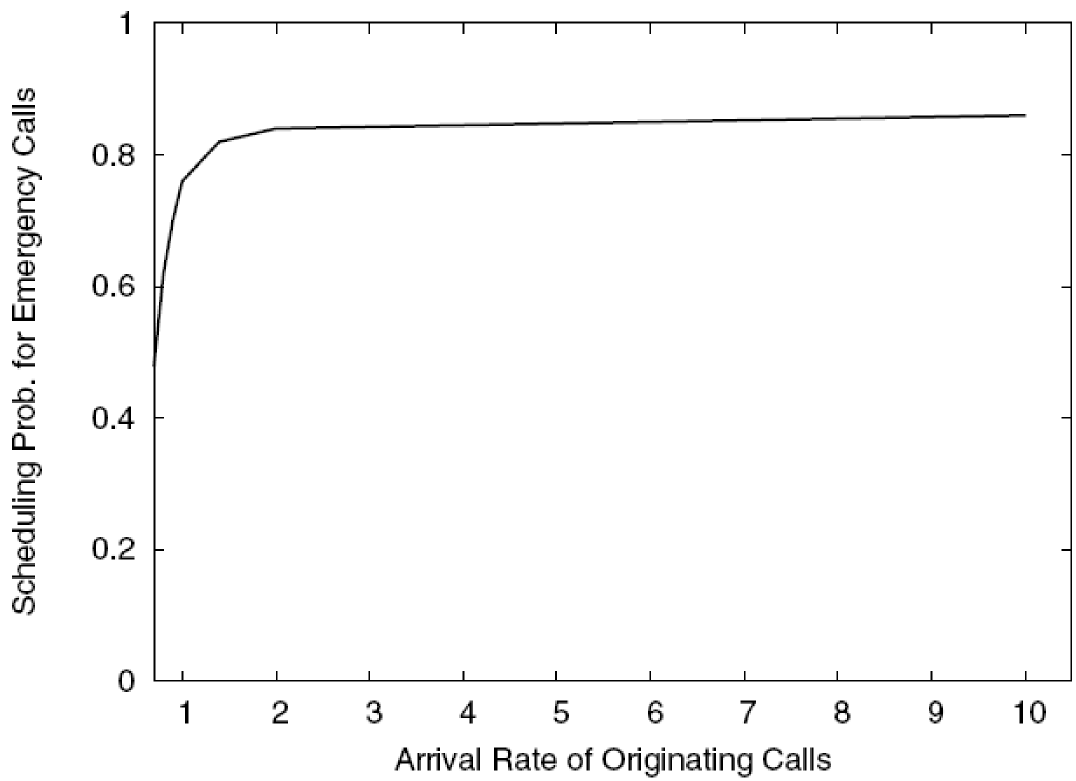
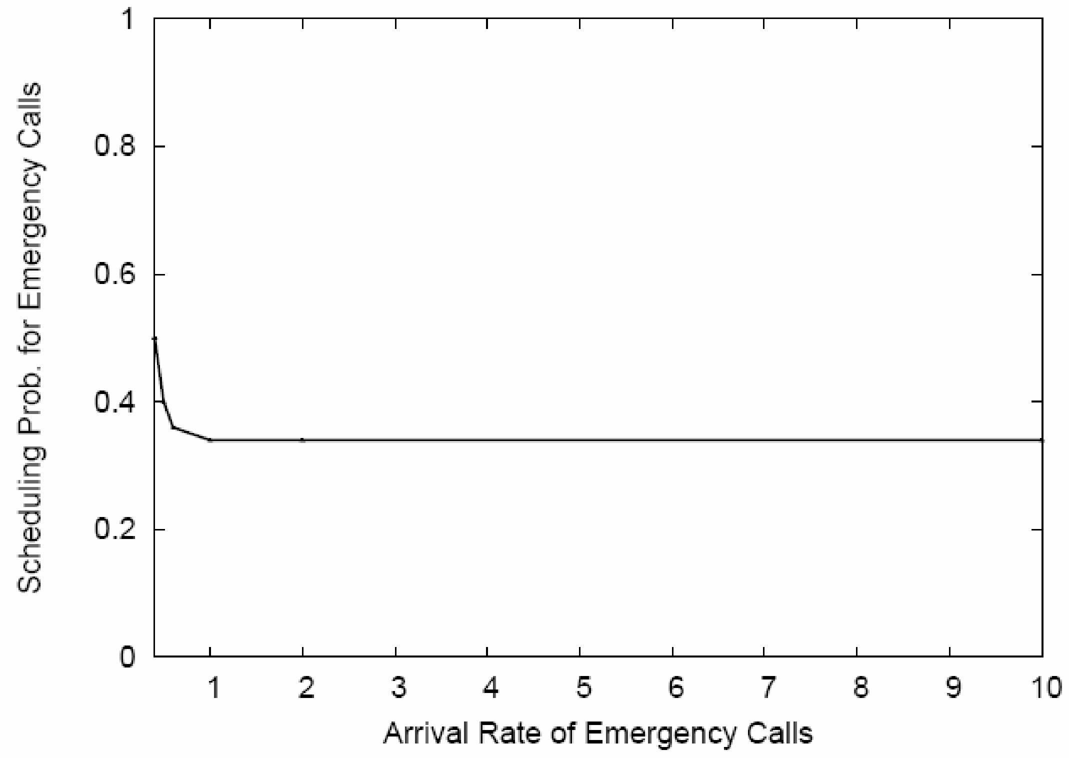
Examples

- Low emergency load, admit 90%.
  - As public load increases, P_s increases.
  - Much higher than the Nyquetek 25%.



Examples

- Public fixed, emergency varies.
  - Scheduling probability decreases to keep public utilization at 70%.



Packet-Switched Networks

- Per-packet QoS is much more complicated than for call admission.
- There are various QoS requirements
  - Packet loss probabilities
  - Delay (average, max, statistical bounds)
  - Delay variation
  - Throughput
- And the requirements are different depending on the application
  - Voice over IP
  - Video
  - Web
  - File sharing, downloads

Packet-Switched Networks

- Service delivery is also very different
  - Unregulated Internet service providers
  - Wireless data services from cellular providers
  - Publicly available wireless LAN's
- Service expectations and contracts are also different
  - No guarantees
  - Guaranteed overprovisioning
  - Service differentiation with measurable guaranteed performance
  - Service differentiation without guarantees
  - Unknown – what does your cable modem provider really guarantee?

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Packet-Switched Networks

- Net neutrality debate – even allowing better service to some customers is debated.
  - Google might pay for performance to Google sites to be better.
  - Various debates in Congress over this.

Emergency Services in Packet-Switched Networks

- Internet Engineering Task Force – ieprep working group, 2002-2007
  - Lots of debate between emergency groups, equipment vendors, service providers.
    - Service providers claimed overprovisioning was enough.
  - A few helpful documents resulted, but nothing conclusive.

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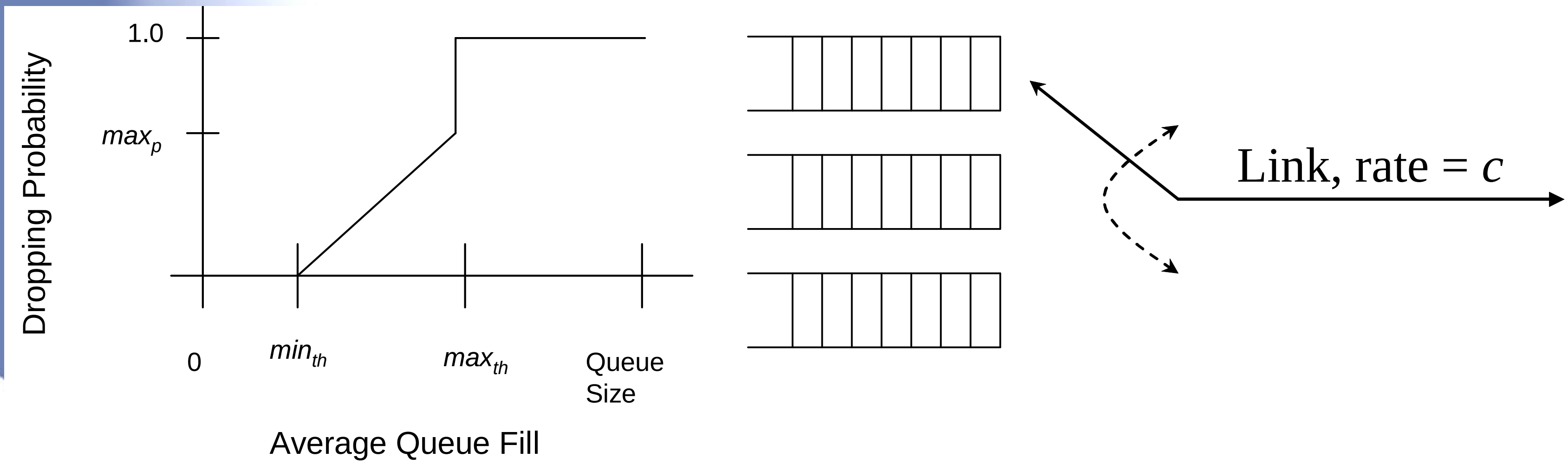
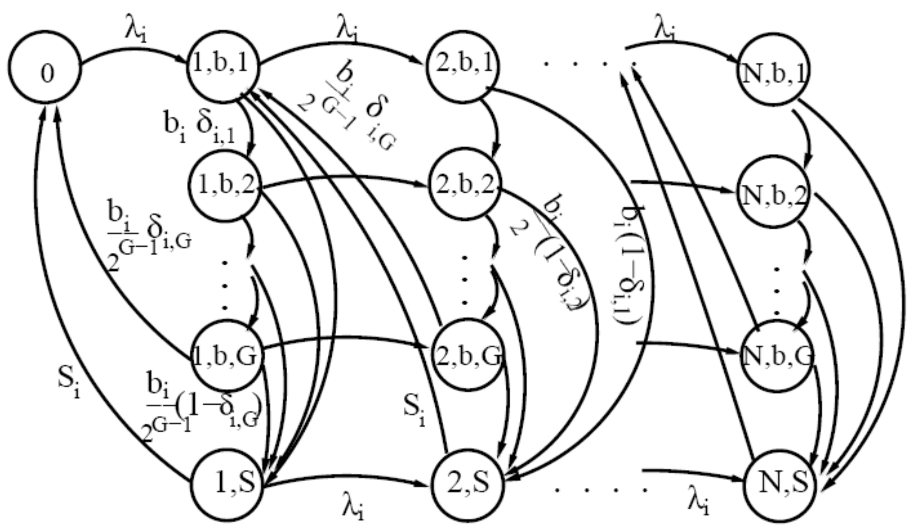
Packet-Switched Networks

- Research
  - To provide better service, packets can be dropped, scheduled, or routed in special ways.
  - We produced results on priority dropping methods.



Packet-Switched Networks

- Research
  - In some environments, like wireless LAN's, one cannot even assume centralized control.
  - So, can nodes compete for resources in a fair way and give emergency users what they need?
    - Use game theory to see if users can find useful equilibrium points.
    - Need a good, scalable model.



Summary

- Emergency services are possible today
  - Public telephone
  - Wireless telephone
- Packet-switched services are scarce
  - This may limit the future usefulness of those networks for emergency purposes.