Systematic Adaptation to Network Resource Constraints in Coalition C2 Environments

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Agenda

- Networks as constrained resources
- Existing work on adaptive networking
- Proposed systems model
- Proposed experimentation campaign
- Conclusion

State of Coalition C2 Networks

Requirements for high-bandwidth and real-time applications

- Video streams, voice, imagery, telemedicine, radiological/biometric data, telemetry, ...

Existing data communications technology

- Legacy terrestrial radio and tactical satellite
- COTS: 802.11, 802.16, 802.20, commercial satellite, ...

Current Solution: QoS

Simple QoS: Routing Queues

- Static prioritization of hosts or services

Enterprise QoS: IntServ and DiffServ

- Use of Class/Type fields in IP
- Can specify end-to-end or per-hop behavior

MPLS: Multi-Protocol Label Switching

- Not QoS; a *QoS-enabling* technology
- Virtual Circuit-Switching, allocates resources

Networks in the Ideal World…

- Allow applications to negotiate traffic requirements with the network, and adapt real-time to available resources
- Allow users to specify service-layer requirements that inform the application and network layers of required/desired resource requirements

Adaptive Networking

The dynamic adjustment of both network infrastructure and application traffic to accommodate changing demands using available resources.

Augments capabilities of QoS technologies

- Application traffic adjusts to network conditions
- Based on criteria, not classifiers
- Optimizes to best fit/compromise of all users' information requirements

Adaptive Networking

Three primary approaches

- Application-aware: Application participates in resource negotiation, and adapts its traffic based on feedback from the network
- Application-transparent: Application unaware of adaptive network; network performs traffic adaptation on behalf of application
- User-aware: Human-in-the-loop approach; user is able to adapt resource usage based on presented feedback from the network

Adaptive Networking

Recurring themes

- Negotiation with network for resources
- Specify ranges, not single values
- Data quality can adapt to network conditions

Interesting notions

- Tung and Kleinrock – rewards system
- Helmy – scale by popularity and density

Current Limitations

- Resource negotiation is based on network parameters (e.g. peak/average bandwidth, latency, packet loss, ...) rather than service-level requirements
- Systems treat applications independently, cannot aggregate resource requests
- Built on standard IP networks, do not evaluate alternate data paths

Systematic Adaptation

- View services as a network, not a list
- Dynamic adjustment of both network and applications
- Resource negotiation based on complex service-level parameters

Systematic Adaptation

Requirements for a systems approach

- Hierarchical/Layered model
- Quantified relationships between layers
- Variety of adaptive mechanisms

Layered Model

Existing work on layered models

- Bauer & Patrick – Extension to OSI model
- Siller & Woods – Three layer model

Proposed four-layer model

- Physical – link medium, distance, RF
- Logical – network of endpoints and routers
- Application – traffic flows between endpoints
- Service – user view of complex application set

Layer Relationships

Translate user- or service-layer requirements into application and network parameters

- Service responsiveness maps to latencies (processing, buffering, transmission, etc)
- Multimedia quality requirements (Service)
  → Resolution, sample rate, etc (Application)
  → Bandwidth, jitter, packet loss (Network)
  → Link distance, frequency (Physical)

Adaptive Mechanisms

Adaptive network can apply a range of mechanisms based on knowledge of user requirements and network state

- Aggregate data streams for similar requests
- Offload lower priority traffic onto alternate data paths
- Offer tradeoffs to user (video resolution vs. frame rate)

Experimental Scenarios

Derived from earlier requirements

- Negotiation based on service-level requirements
- Aggregation of resource requests
- Evaluation and use of alternate data paths

Designs based on existing campaign

- USSOCOM-NPS Field Experimentation Program
- PI's: Dr. Dave Netzer, Dr. Alex Bordetsky

Sample Experiment

Operator in Tactical Operations Center requiring video feed from a remote UAV

Statement of requirements:

> "I need video with sufficient quality to identify and track a moving vehicle from a low-flying UAV. This video must be presented to me within five seconds of real-time so that I can provide feedback to operators on the ground. I will be viewing this video in a remote command center at least 10km away from the UAV ground station."

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- Sufficient quality to identify… → maximize video resolution
- … and track a moving vehicle → maximize frame rate
- Within five seconds of real-time → minimize delay
- At least 10km away → maximize distance

Layered Parameters

Service layer
- Maximize resolution (identify vehicle)
- Maximize frame rate (track moving vehicle)
- Minimize delay (within five seconds)
- Maximize distance (at least 10km)

Application layer
- Resolution – video quality vs. bandwidth
- Frame rate – video quality vs. bandwidth
- Buffer size – latency vs. jitter

Logical network layer
- Bandwidth, jitter, packet loss – video quality

Physical network layer
- Link distance, choice of medium – bandwidth, packet loss, range

Experiment Design

"Tunable Knob" approach

- User can modify any malleable parameter
- User's goal is to optimize to requirements
- Experimenter's goal is to force user to make intelligent compromises

Possible extension

- Use PSI model for criteria optimization

Conclusion

Take-aways

- Systems approach enables holistic adaptation
- Many of the puzzle-pieces exist in limited form
- Need for a process to translate service req's

Future work

- Developing and performing campaign of experimentation to study further
- Develop prototype models and systems

Questions?

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