Distributed Adaptation for Heterogeneous Networks

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Roadmap

» Adaptation and network heterogeneity
- Our approach: distributed adaptation
- Advantages of distributed adaptation
- Conductor: design and implementation
  - Architecture
  - Stream Management
  - Reliability
  - Planning
  - Security

The Need for Adaptability

- Networks: not always fast and free
  - Bandwidth, latency, jitter, $$, security, reliability
- Applications typically assume a minimum level of network service
  - Cost vs. benefit imbalance
- Goal: applications should provide gracefully degraded service

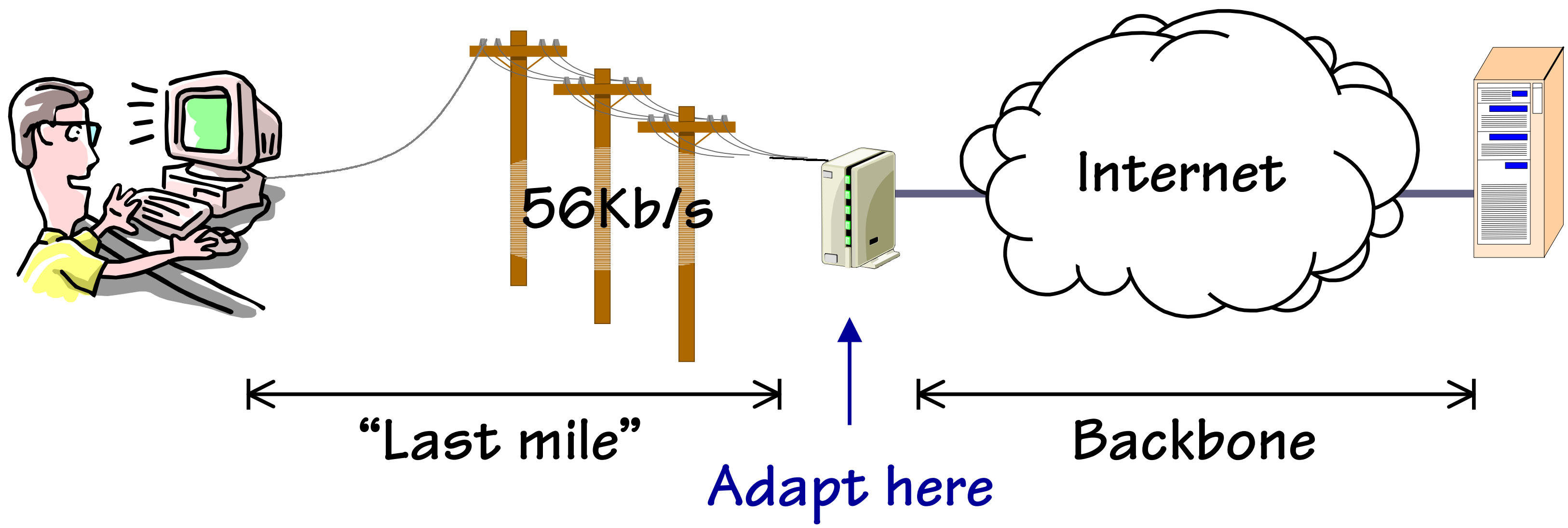
Adaptive Software:

Software that can tailor its services to constraints in available resources and user expectations.

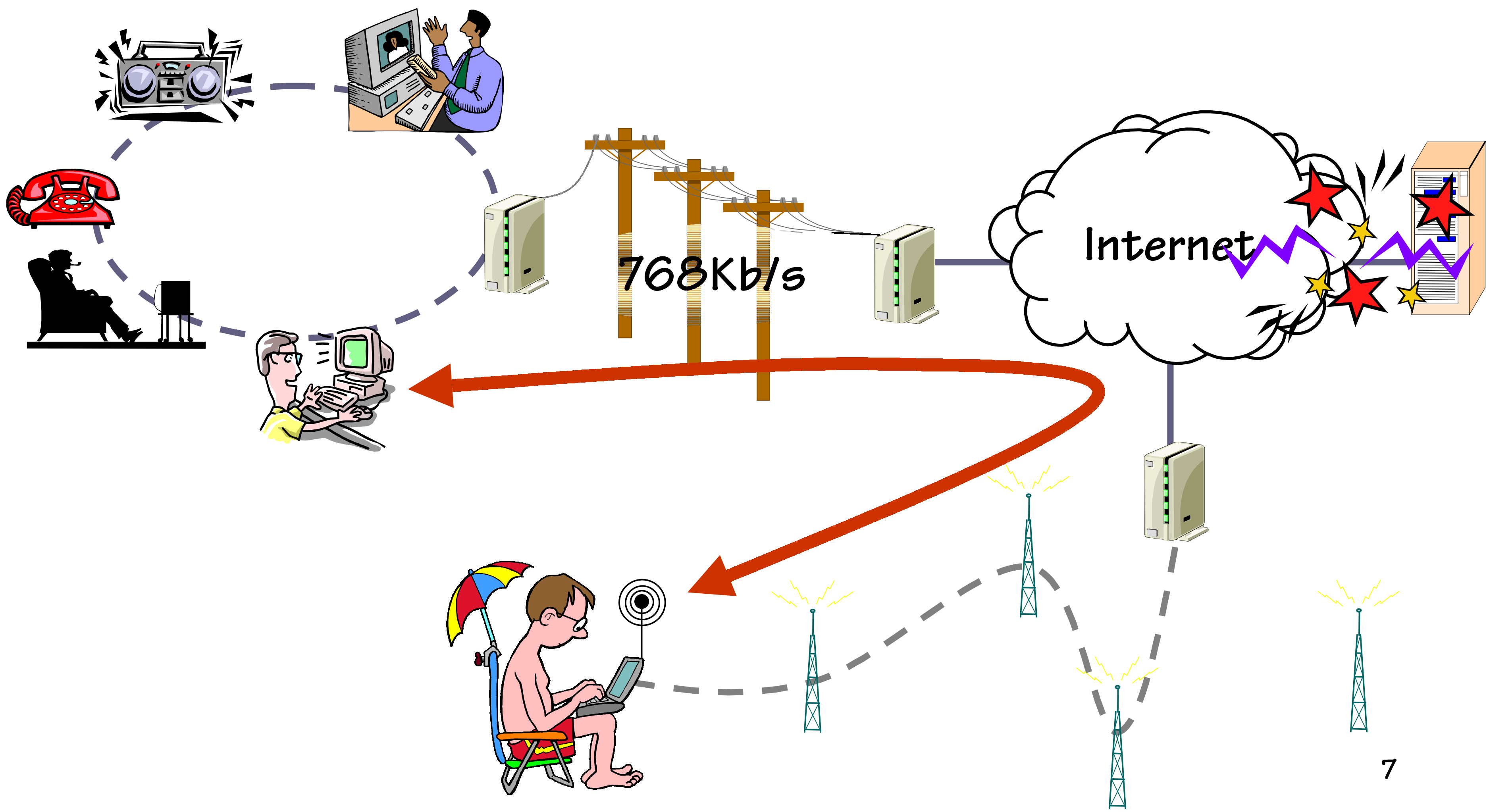
Enabling Adaptability

- Adapt application-layer protocols from within the network
  - Compress, encrypt, prefetch
  - Distill a video stream to black-and-white
  - Remove advertisements from web pages
  - Prioritize interactive browsing over downloads
  - Power down wireless interface during predicted query response latency
- Is this heresy?

Trend: Network Heterogeneity



Trend: Network Heterogeneity



Adaptation in Heterogeneous Networks

- Multiple constrained links
- Multiple types of constraints
- Conditions difficult to predict
- Many possible adaptations
- Many possible locations for adaptation

Roadmap

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- » Our approach: distributed adaptation
- Advantages of distributed adaptation
- Conductor: design and implementation
  - Architecture
  - Stream Management
  - Reliability
  - Planning
  - Security

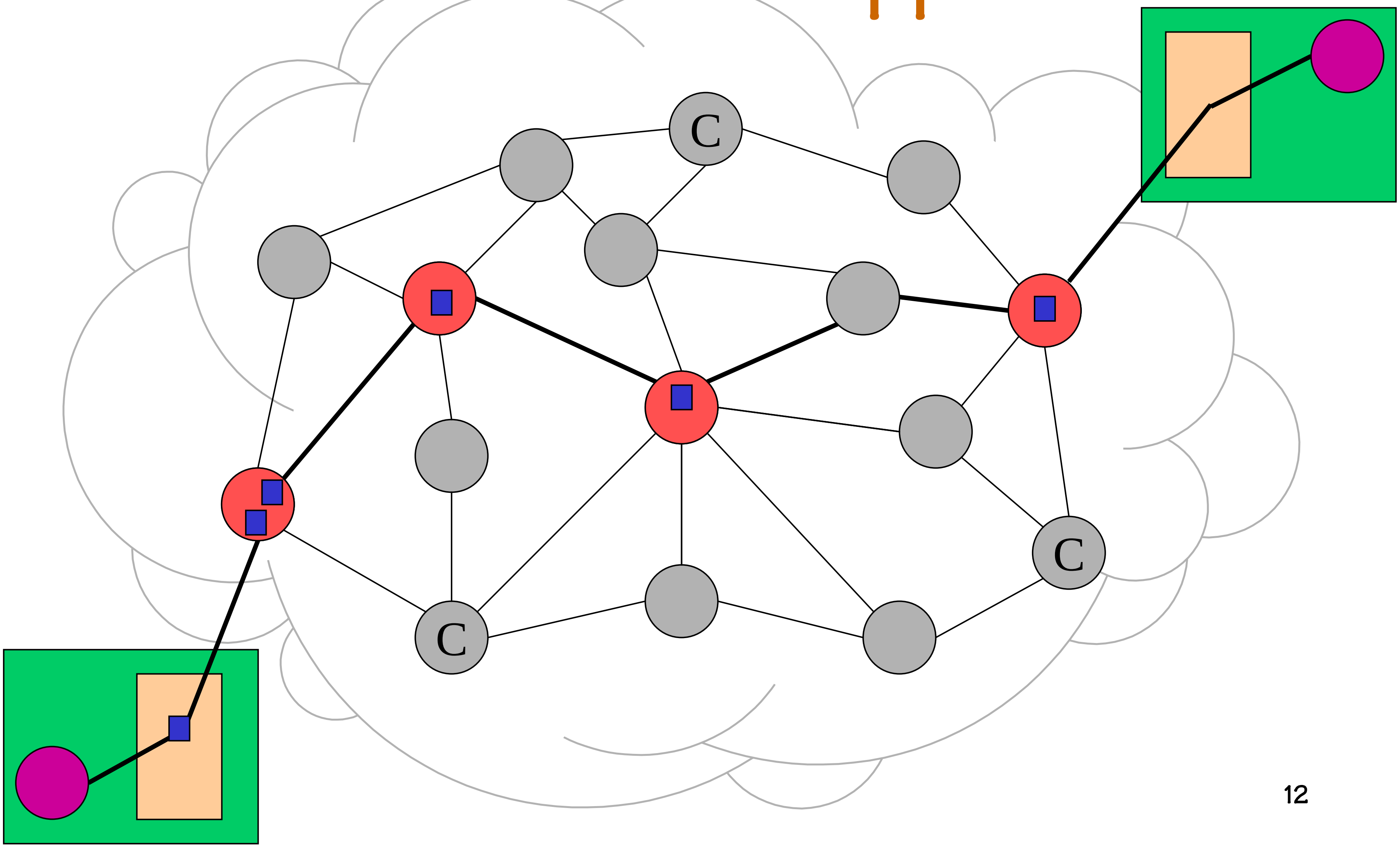
Distributed Adaptation

- Goal: allow applications to degrade gracefully in heterogeneous networks
- Required:
  - Multiple adaptations
  - Distributed within the network
  - Coordinated

The Conductor Approach

- Arbitrary (and potentially lossy) adaptation of application-level protocols
  - Reliable connection-oriented streams
- Dynamic selection of adaptive code modules at enabled points in the network
  - Conductor is incrementally deployable
- Application transparent, but not user transparent
  - User controllable

The Conductor Approach



Challenges Met by Conductor

- New reliability model required
  - Exactly-once delivery of bytes no longer makes sense
- Enable coordinated adaptation
  - Multi-node planning in a low-performance network
- Security without de facto infrastructure
  - Protect control over adaptation <u>without</u> a ubiquitous authentication architecture

Roadmap

- Adaptation and network heterogeneity
- Our approach: distributed adaptation

» Advantages of distributed adaptation

- Conductor: design and implementation
  - Architecture
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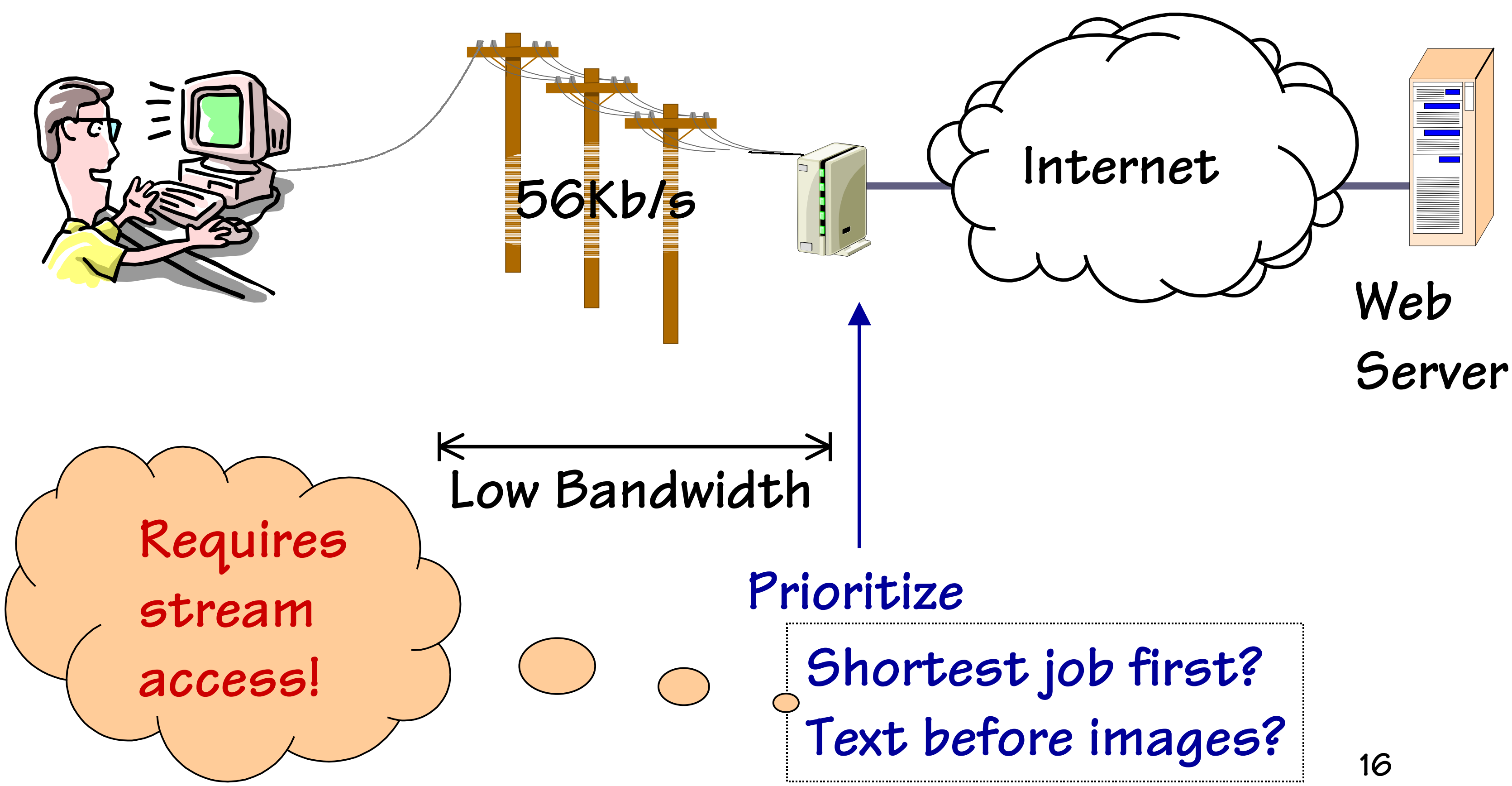
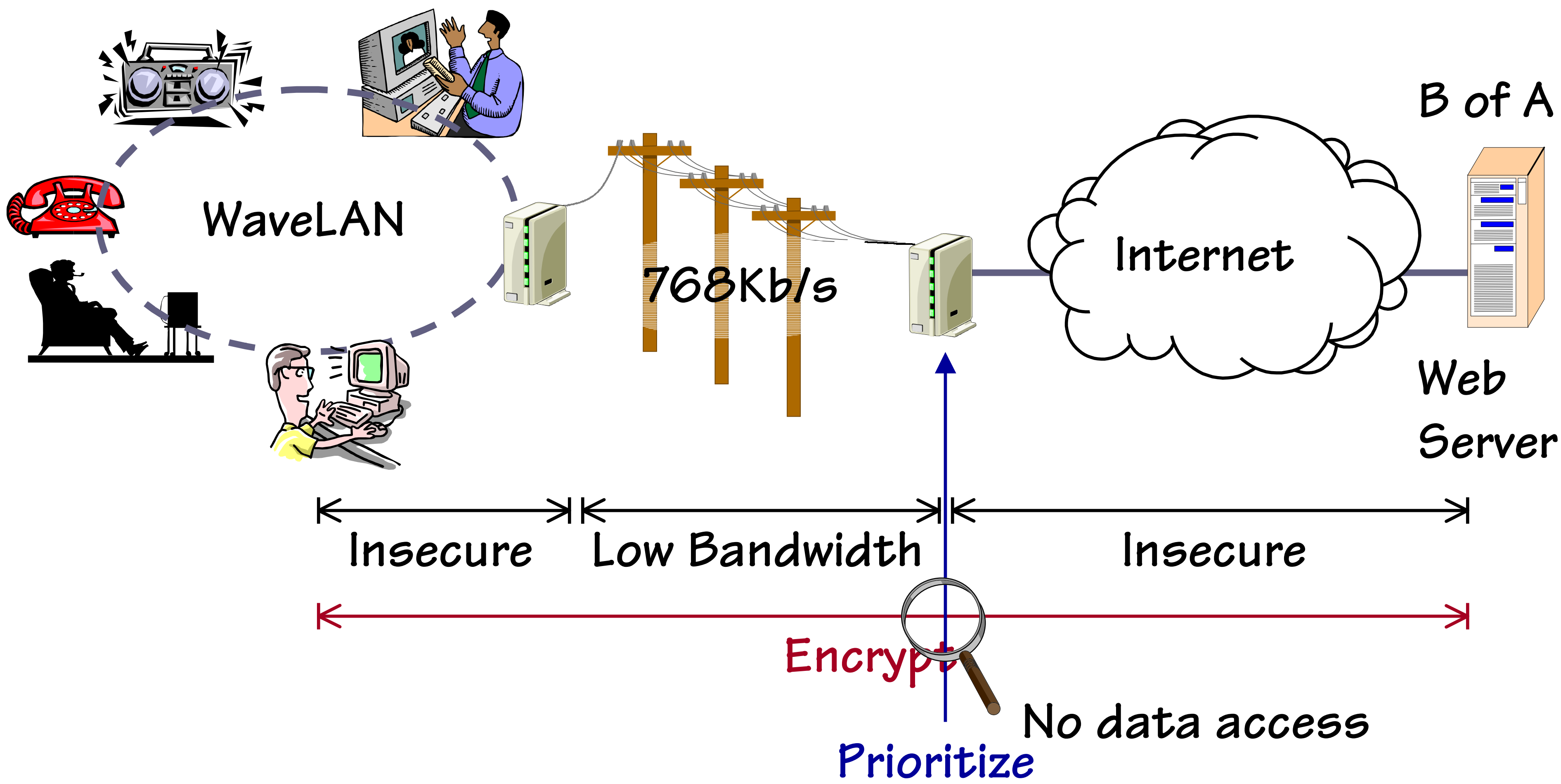
Case Study #1

Secure, Low-Bandwidth Web Browsing

Case Study #1

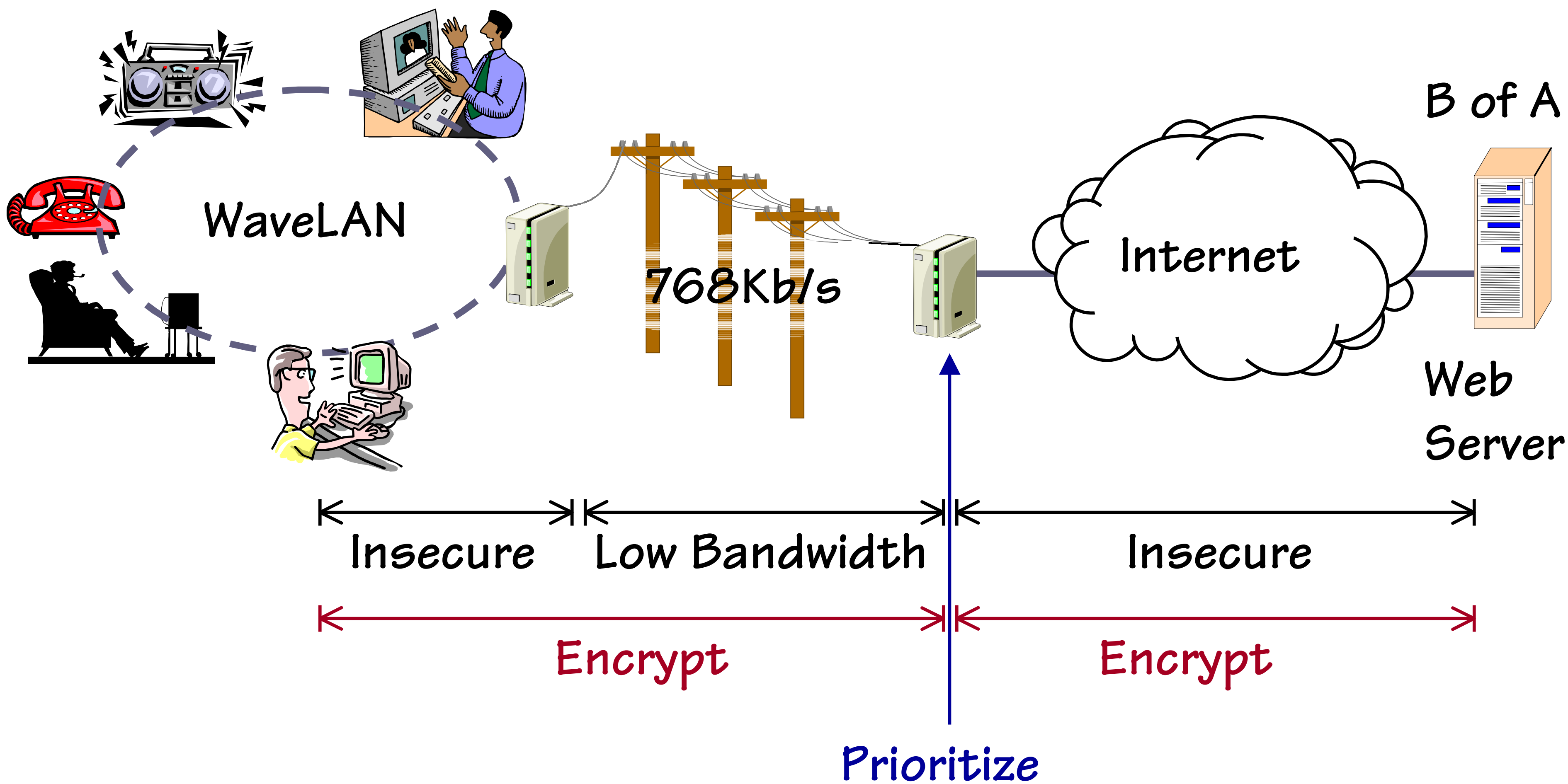

56Kb/s
Internet
Web
Server
Low Bandwidth
Requires
stream
access!
Prioritize
Shortest job first?
Text before images?

Case Study #1



WaveLAN
768Kb/s
Internet
B of A
Web
Server
Insecure
Low Bandwidth
Insecure
Encrypt
No data access
Prioritize

Case Study #1

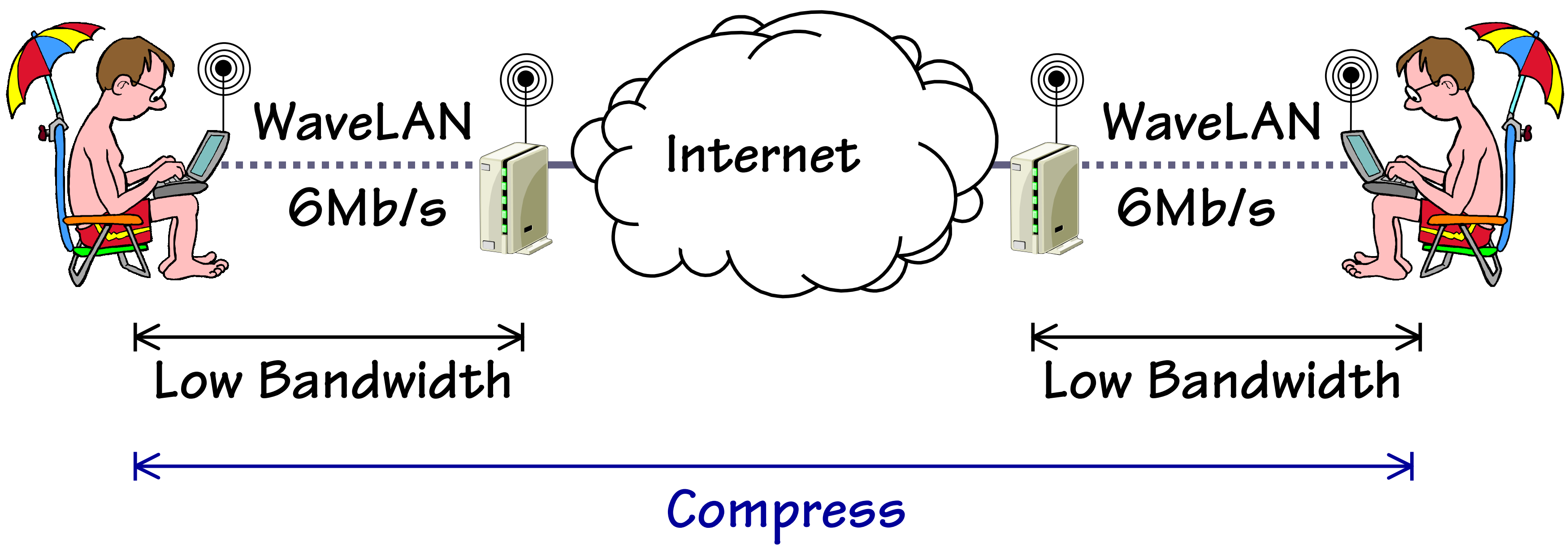


WaveLAN
768Kb/s
Internet
B of A
Web
Server
Insecure
Low Bandwidth
Insecure
Encrypt
Encrypt
Prioritize

Case Study #2

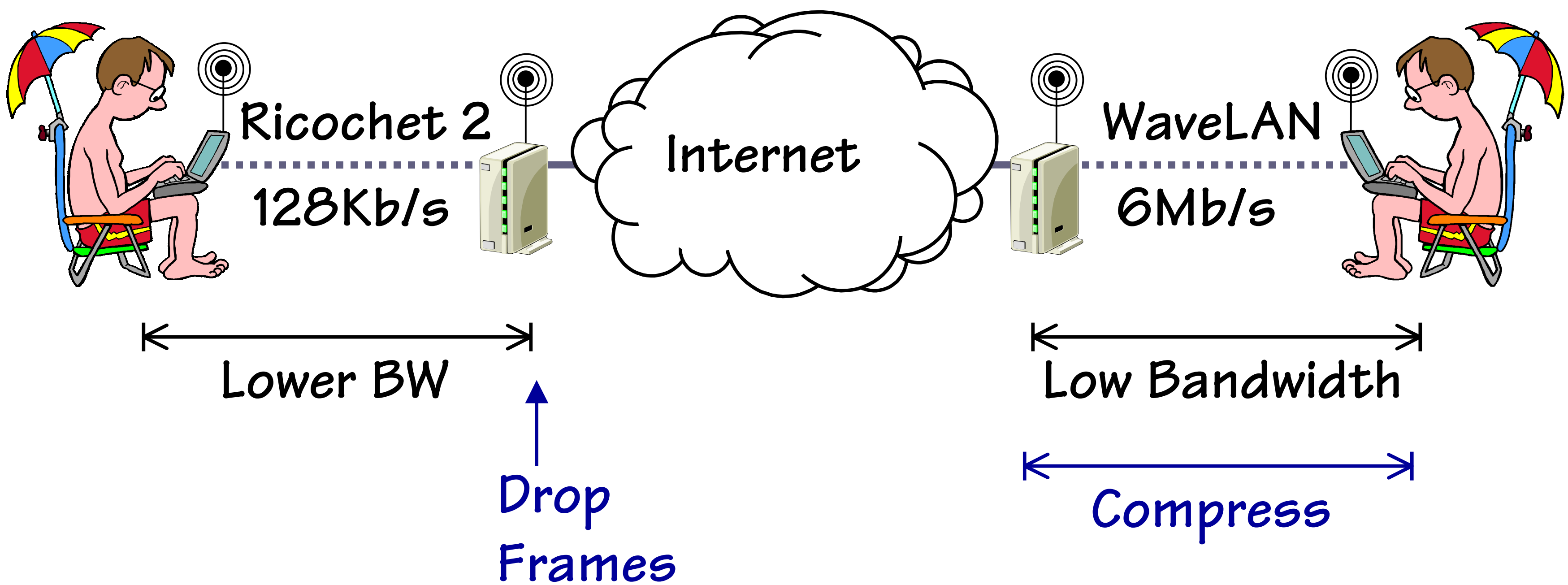
Wireless to Wireless Video Streaming

Case Study #2

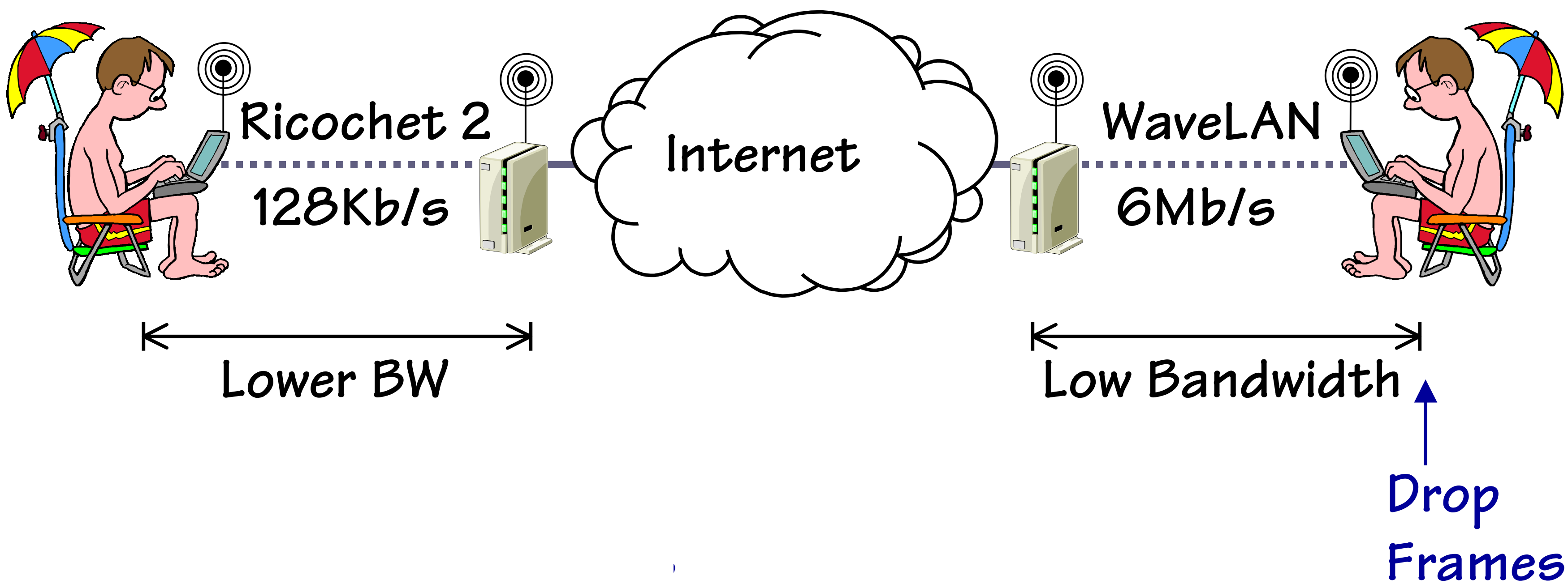


WaveLAN
6Mb/s
Internet
WaveLAN
6Mb/s
Low Bandwidth
Low Bandwidth
Compress

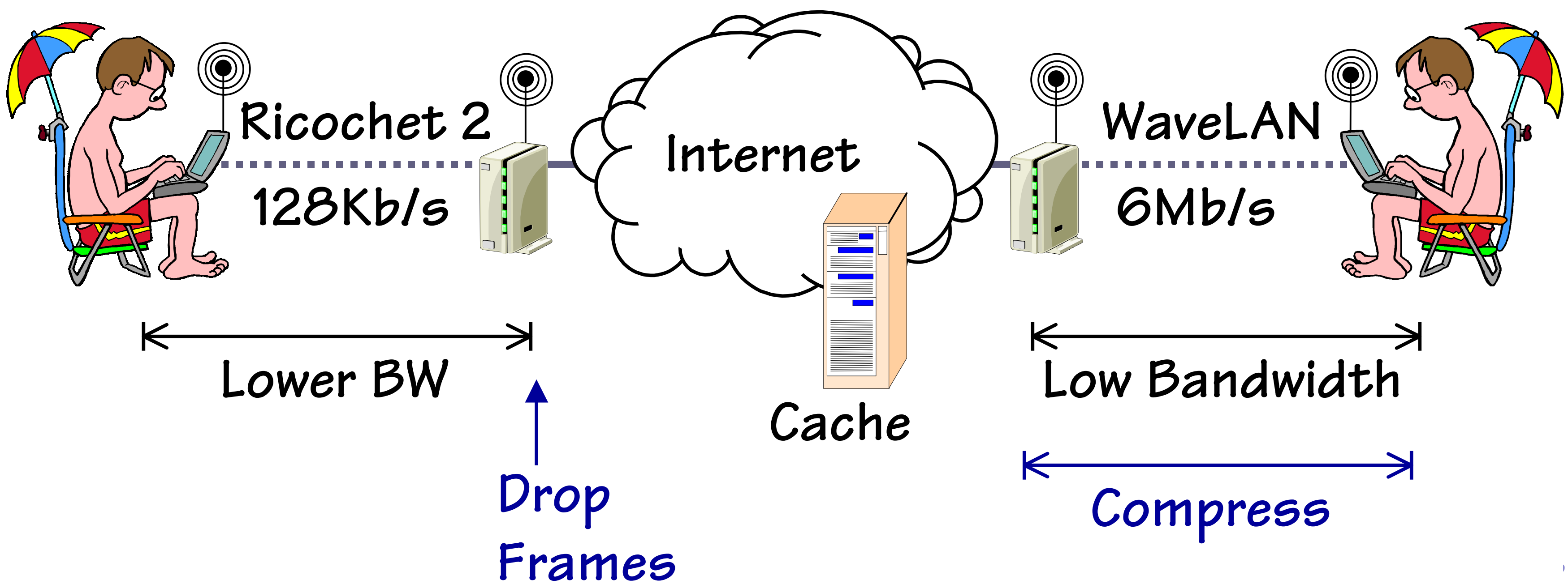
Case Study #2


Ricochet 2
128Kb/s
Internet
WaveLAN
6Mb/s
Lower BW
Low Bandwidth
Drop
Frames
Compress

Case Study #2


Ricochet 2
128Kb/s
Internet
WaveLAN
6Mb/s
Lower BW
Low Bandwidth
Drop
Frames

Case Study #2



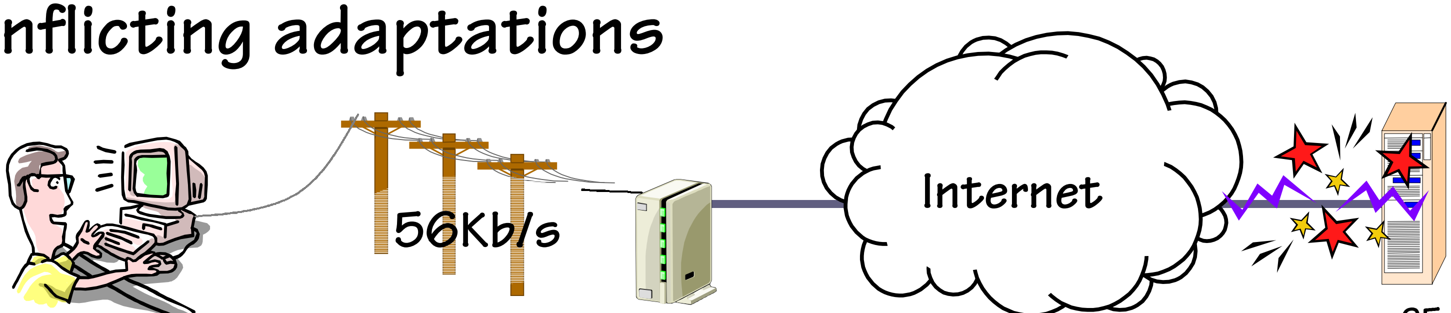
Ricochet 2
128Kb/s
Internet
Cache
WaveLAN
6Mb/s
Lower BW
Low Bandwidth
Drop
Frames
Compress

Case Study Results

- Multiple adaptations
- Multiple points of adaptation
- Coordination required!!!
- Must understand end-to-end network characteristics

Adaptation Deployment Constraints

- Limited node resources
  - Load balancing, palmtops
- Location, location, location
  - Proximity means agility
  - Hardware access
  - Leveraging topology
- Conflicting adaptations



Other Approaches

- Situation-specific applications
  - Palm clipping apps
  - Text-based web browsers

» May require specialized applications

» Requires user diagnosis and intervention

Other Approaches

- Adaptable applications
  - Odyssey [Noble]
  - Rover [Joseph]
  - Application partitioning [Kottmann][Watson]

    » Requires application modifications

    » Application writer must foresee and understand possible network conditions

Other Approaches

- Adaptation as a network service
  - Boosting existing protocols
    - Snoop [Balakrishnan], Protocol Boosters [Mallet]
  - Protocol Transformers
    - Transformer Tunnels [Sudame, Badrinath]
    - Proxy architectures [Fox, Gribble] [Zenel]
  - Active Networks
  - » Lack coordination and reliability needed for arbitrary multipoint adaptation

Roadmap

- Adaptation and network heterogeneity
- Our approach: distributed adaptation
- Advantages of distributed adaptation

» Conductor: design and implementation

  – Architecture
  – Stream Management
  – Reliability
  – Planning
  – Security

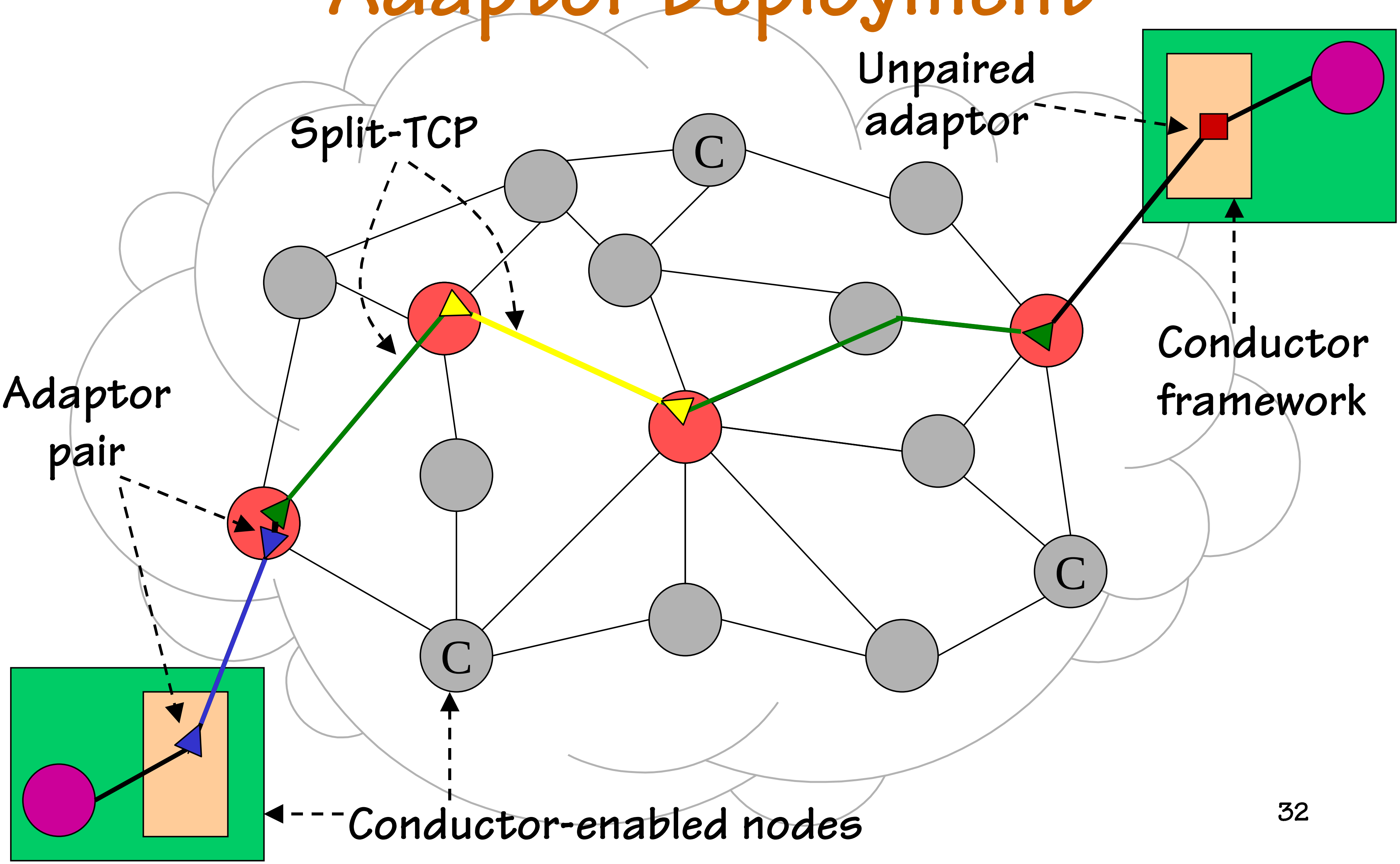
Conductor Architecture

- Components: framework and adaptation modules
- Adaptation framework
  - Transparent interception and routing
  - Node/link status monitoring
  - Distributed planning and deployment
  - Adaptor runtime environment

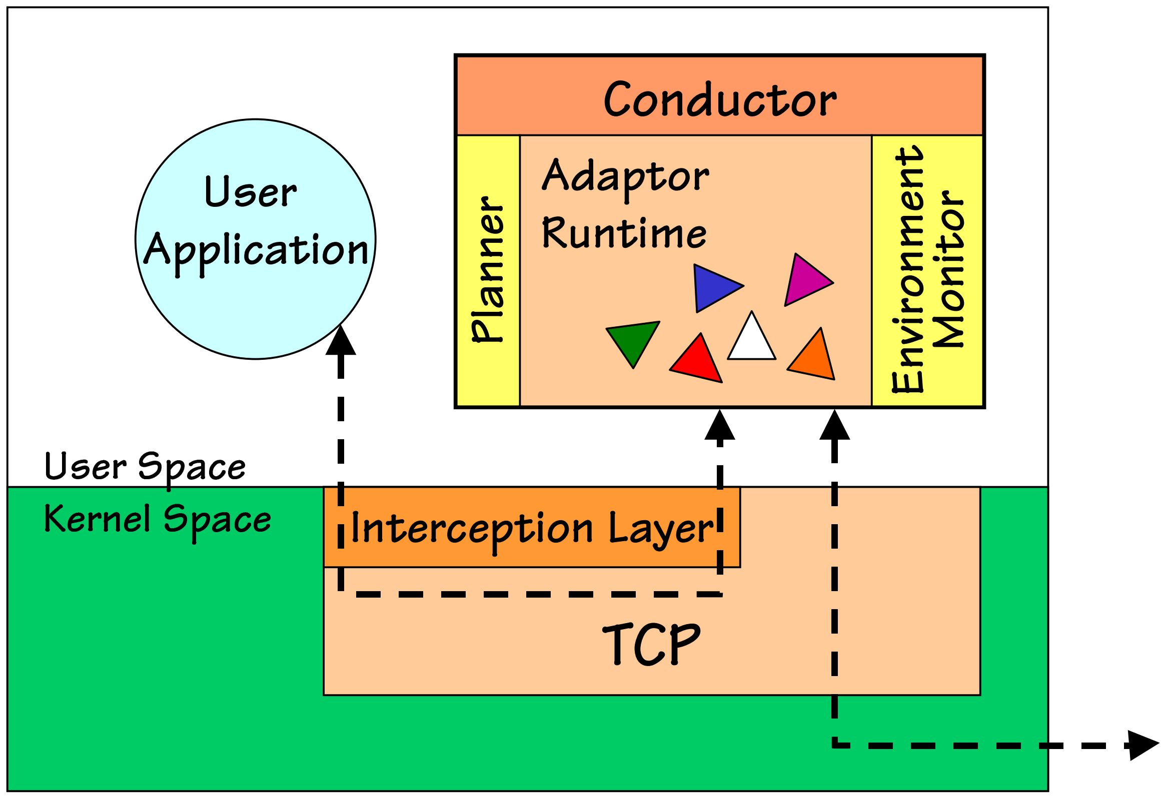
Conductor Architecture

- Adaptor modules
  - Operate on data stream
    - Arbitrary modifications allowed
  - Easily extensible set
  - Frequently paired
  - Composable
  - Stored on Conductor-enabled nodes

Adaptor Deployment



A Conductor-Enabled Node

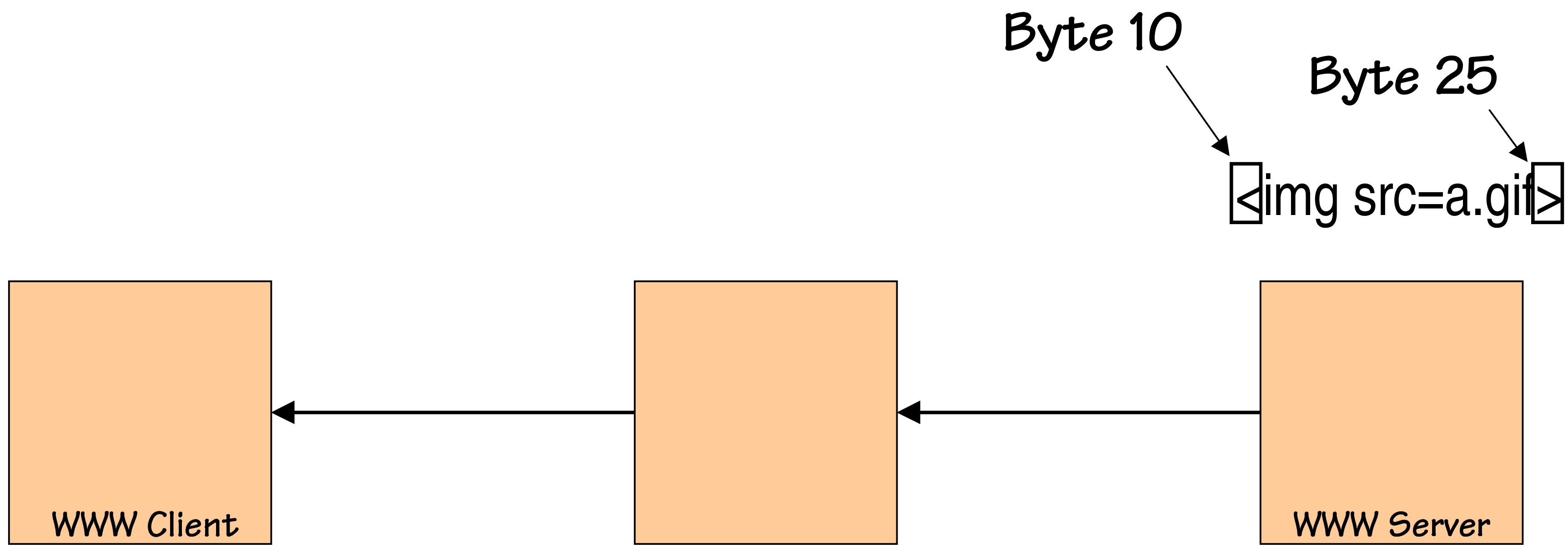


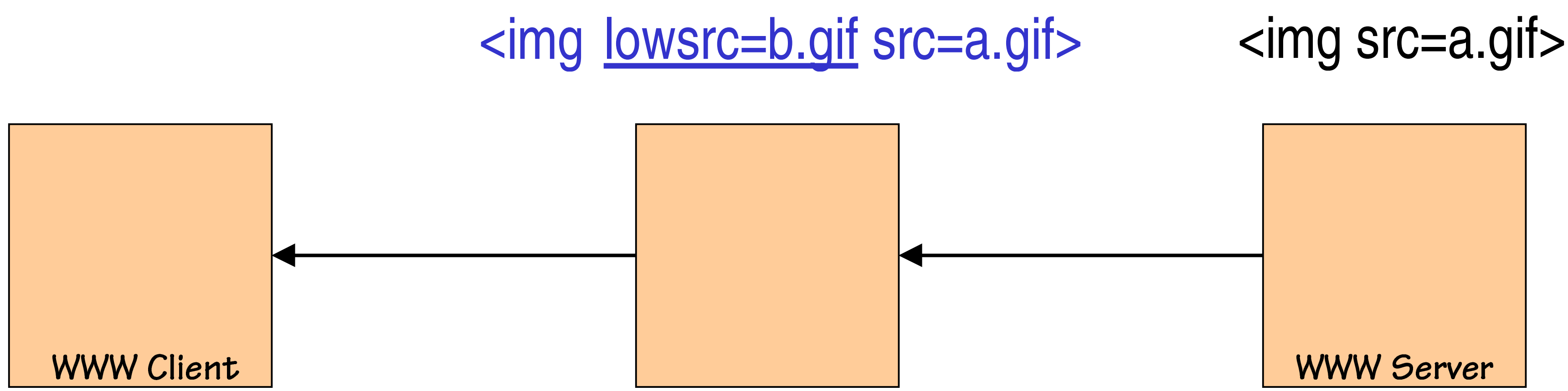
Stream Management

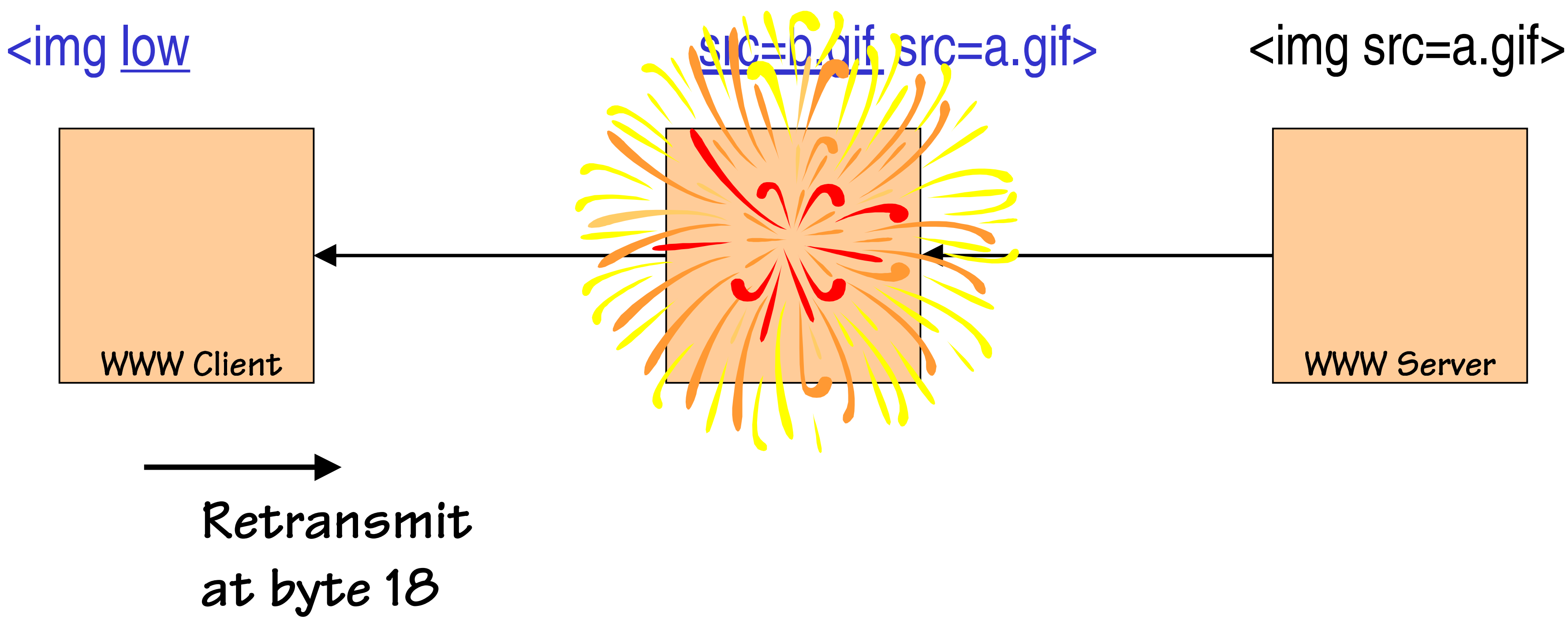
- Capture at socket level
  - Maintain existing socket API
  - Route through other Conductor nodes
  - Create transparent split-TCP connection
- Stream identification
  - Port numbers
  - Protocol identifier
  - Magic number

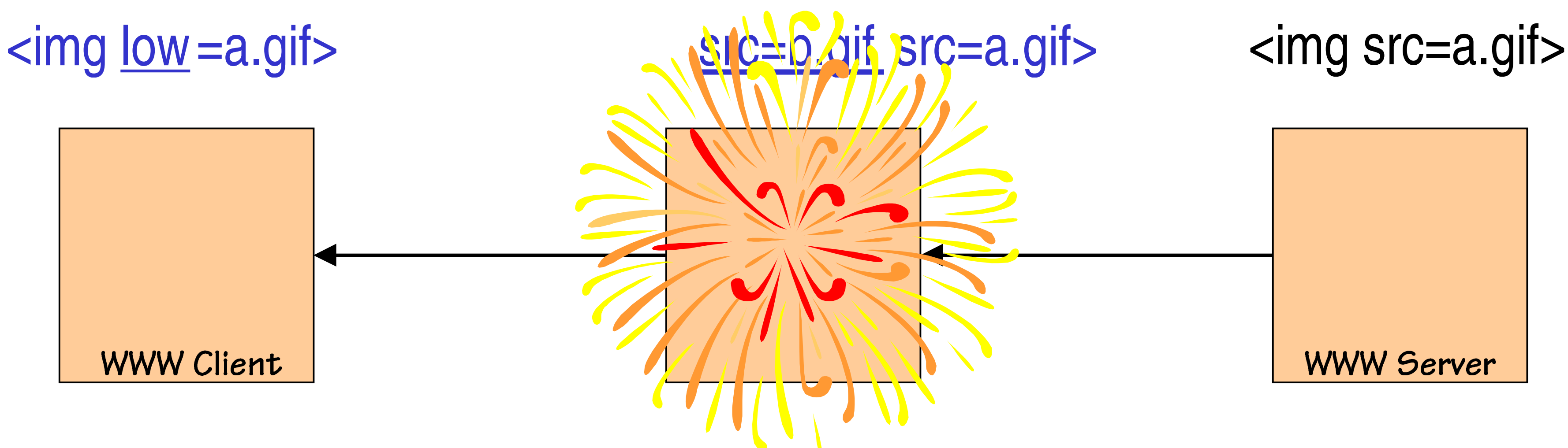
Reliable Transmission

- Goal: Provide adaptation for applications that expect reliable delivery
  - TCP, exactly-once delivery of bytes
- Adaptation can violate typical assumption of data immutability
  - Must allow intentional data loss
  - Exactly-once delivery of transmitted bytes makes no sense


Byte 10
Byte 25
<img src=a.gif>
WWW Client
WWW Server


<img lowsrc=b.gif src=a.gif>
<img src=a.gif>
WWW Client
WWW Server


<img low
src=b.gif src=a.gif>
<img src=a.gif>
WWW Client
WWW Server
Retransmit
at byte 18


<img low=a.gif>
src=b.gif src=a.gif>
<img src=a.gif>
WWW Client
WWW Server

Reliability and Adaptation

- Possible failures: adaptors, nodes, links
- Failure modes
  - Potential data loss
  - Partial adaptation of data
  - Lost adaptor state
  - Adaptor consistency

Reliability in Conductor

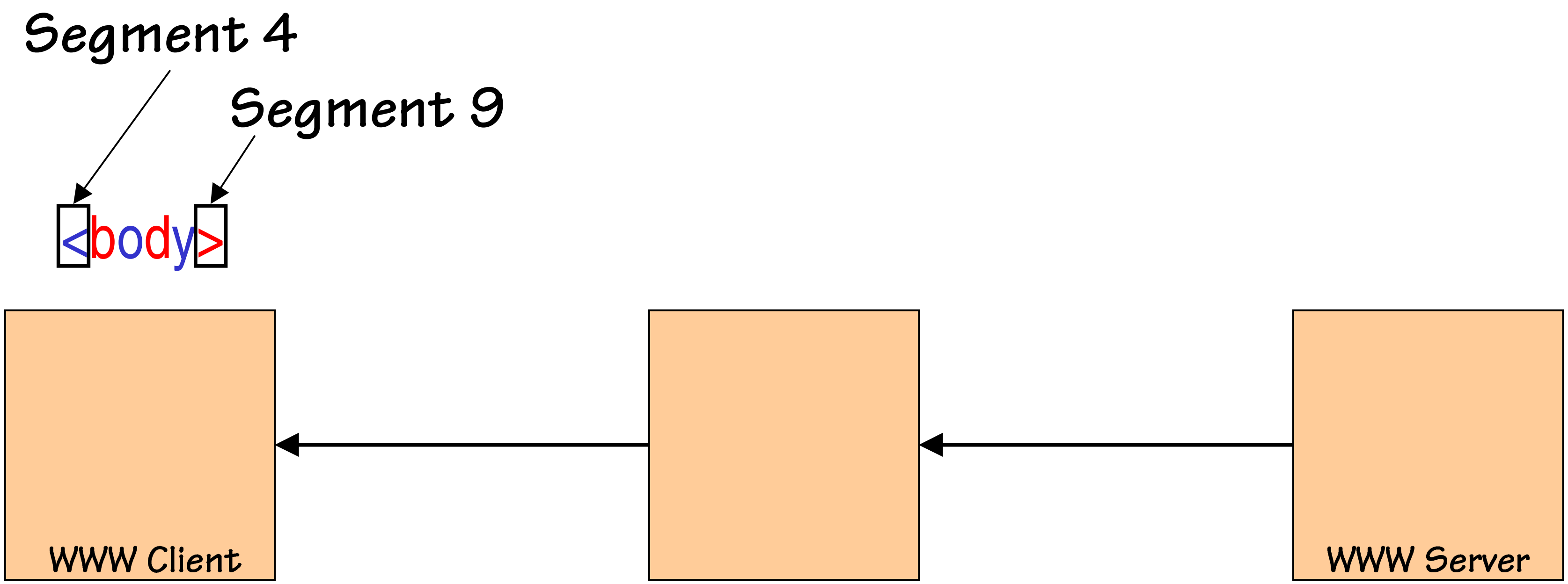
- End-to-end connection built using multi-split-TCP
  - Reliability between points of adaptation
  - Leverage existing technology
  - Adaptation at each node independent of TCP
- Node and link failures detected as TCP connection failures

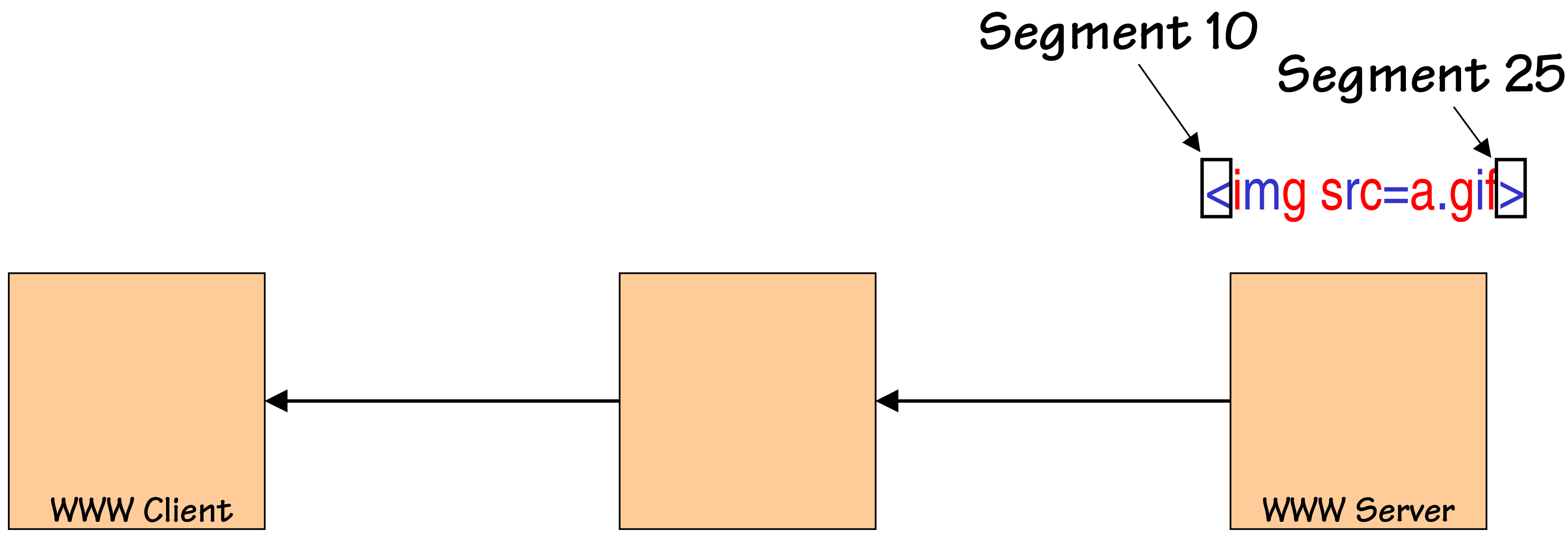
Reliability in Conductor

- How do we know if any data was lost?
- From what point should transmission be restarted?
  - » Need a new unit of retransmission
  - » Maintain some correlation between pre- and post-adapted data

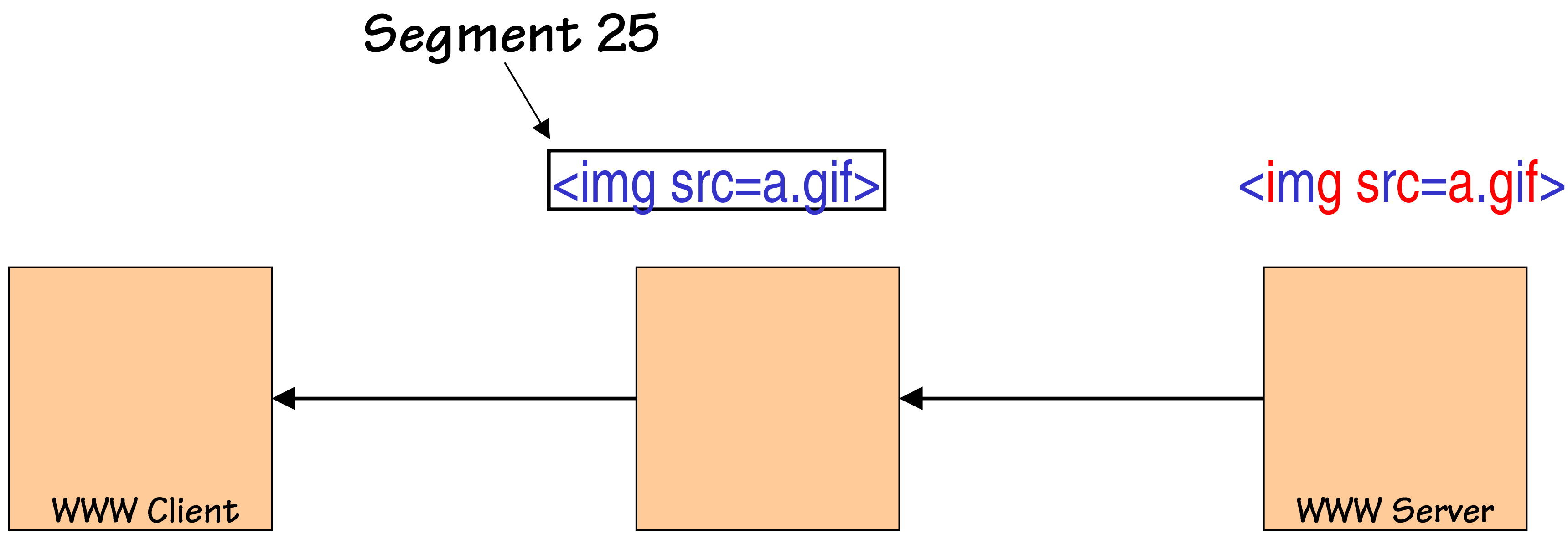
Reliability in Conductor

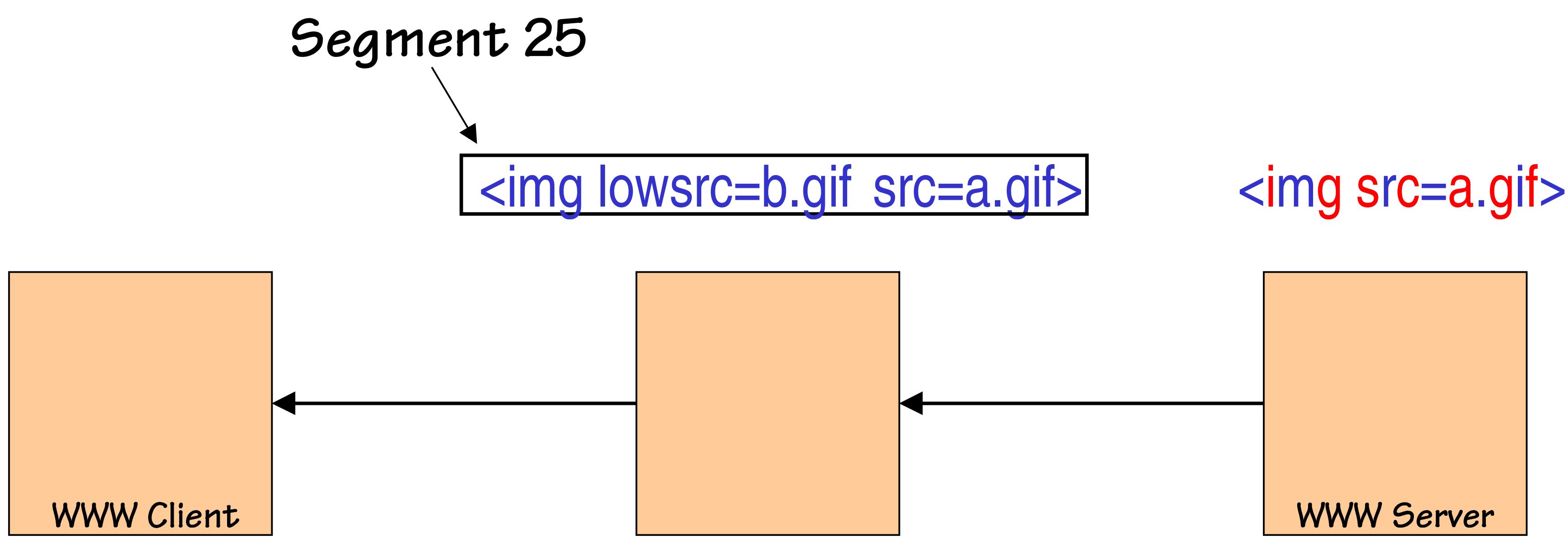
- *Semantic Segmentation*: a semantically meaningful unit of retransmission
  - Divide stream into semantic units
    - Dynamically, based on data type and adaptation
    - No application hints required
  - Preserve semantic meaning of each segment end-to-end
    - Maintained by segment combination
  - Adaptors can express recovery constraints

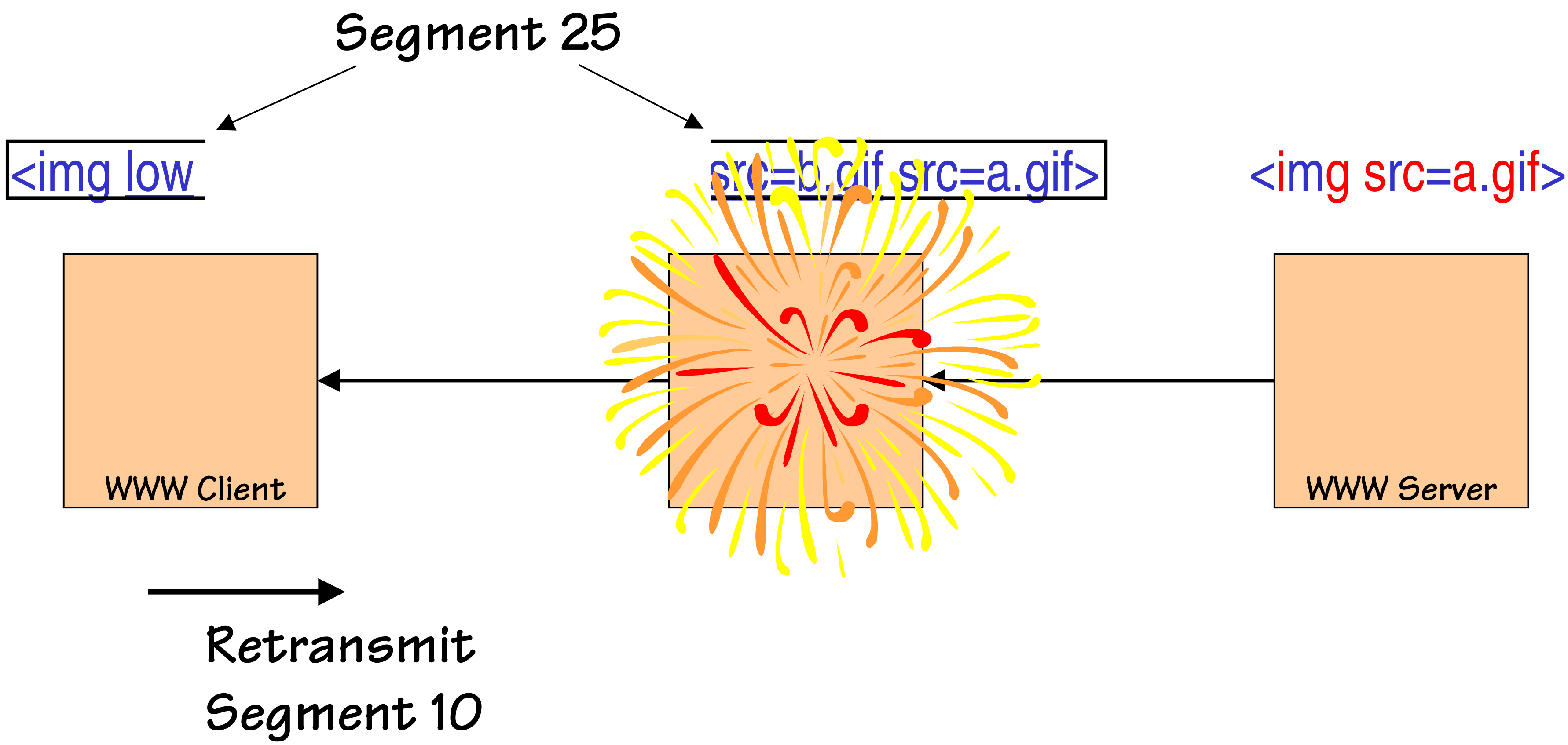

Segment 4
Segment 9
<body>
WWW Client
WWW Server

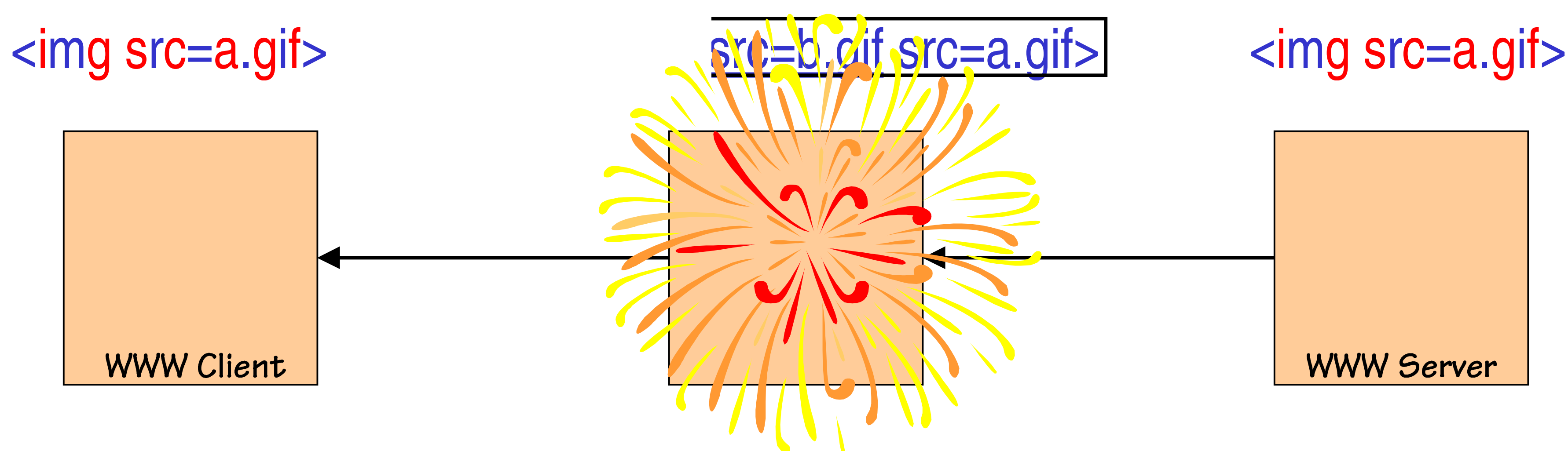


Segment 10
Segment 25
<img src=a.gif>
WWW Client
WWW Server


Segment 25
<img src=a.gif>
<img src=a.gif>
WWW Client
WWW Server


Segment 25
<img lowsrc=b.gif src=a.gif>
<img src=a.gif>
WWW Client
WWW Server


Segment 25
<img low
src=b.gif src=a.gif>
<img src=a.gif>
WWW Client
WWW Server
Retransmit
Segment 10


<img src=a.gif>
WWW Client
src=b.gif src=a.gif>
<img src=a.gif>
WWW Server

Rules of Segmentation

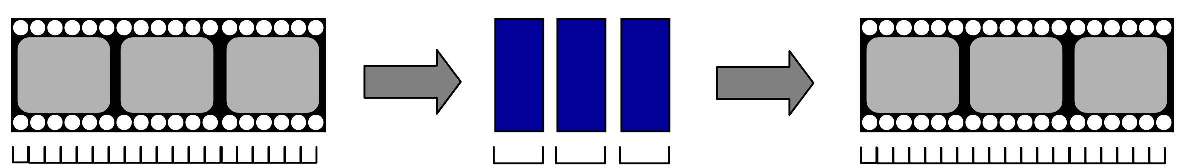
- Start with one byte segments
- Constrain each stream modification to one segment
- Combine segments where necessary
  - Not reversible
  - New segment contains combined semantic meaning
- Final delivery of complete segments only

Reversing Segmentation

- With lossy adaptation, segments must remain until delivery
  - » Must handle this case

<img src=a.gif> → <img lowsrc=b.gif …> → ?

- Lossless adaptation potentially allows original segmentation to be restored
  - » A possible optimization



Benefits of Segmentation

- Service guarantees:
  - Transaction-like adaptation (all or nothing)
  - Exactly-once delivery of some form of each semantic element
- Adaptors can express appropriate points for adaptation changes

Adaptor Selection

- Goal: Select an appropriate set of adaptors for end-to-end conditions
  - Requires a planning capability
- Issues:
  - Speed
    - Planning must occur before data flows
  - Cost
    - Likely presence of low-quality links
  - Coordination
    - Local decisions are not always best

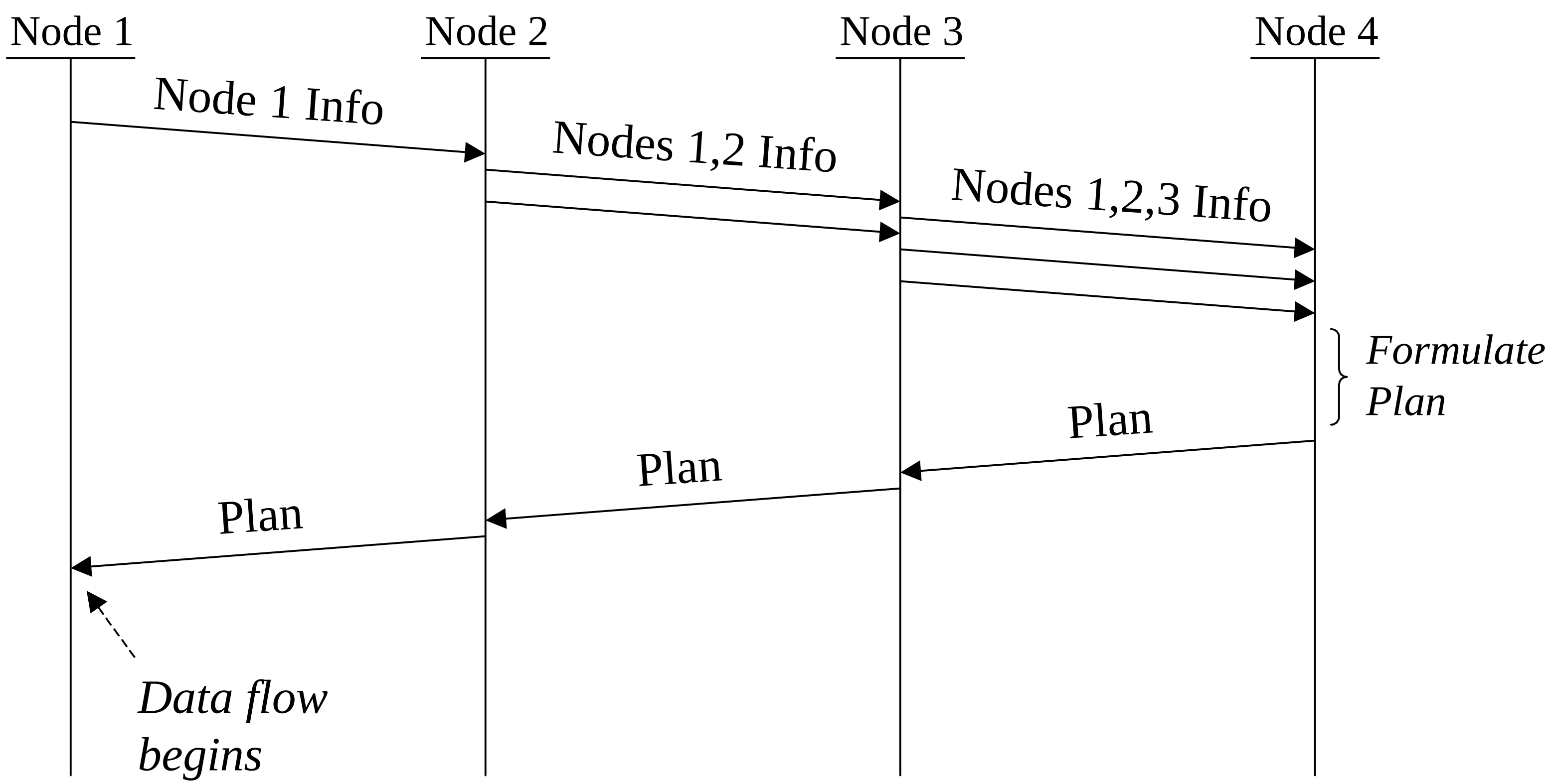
Adaptor Selection

- Inputs to "plan formulation"
  - Node characteristics
    - Resources: CPU, disk, available adaptors
    - Security constraints
  - Link characteristics
    - Bandwidth, latency, etc.
    - Current, historical, expected
  - Data Characteristics
  - User preferences
    - Important data qualities and costs

Planning in Conductor

- Centralized planning
  - Gather all inputs to one location
  - Formulate plan
    - Pluggable architecture
  - Distribute plan
- Reaction to changing conditions
  - Adaptors handle a range of conditions
  - When tolerances are exceeded, replanning occurs

Planning in Conductor



Planning in Conductor

- **Benefits:**
  - Only requires one round trip latency
  - Can plug in any "plan formulation" code
    - Static
    - Template based
    - Heuristic search based

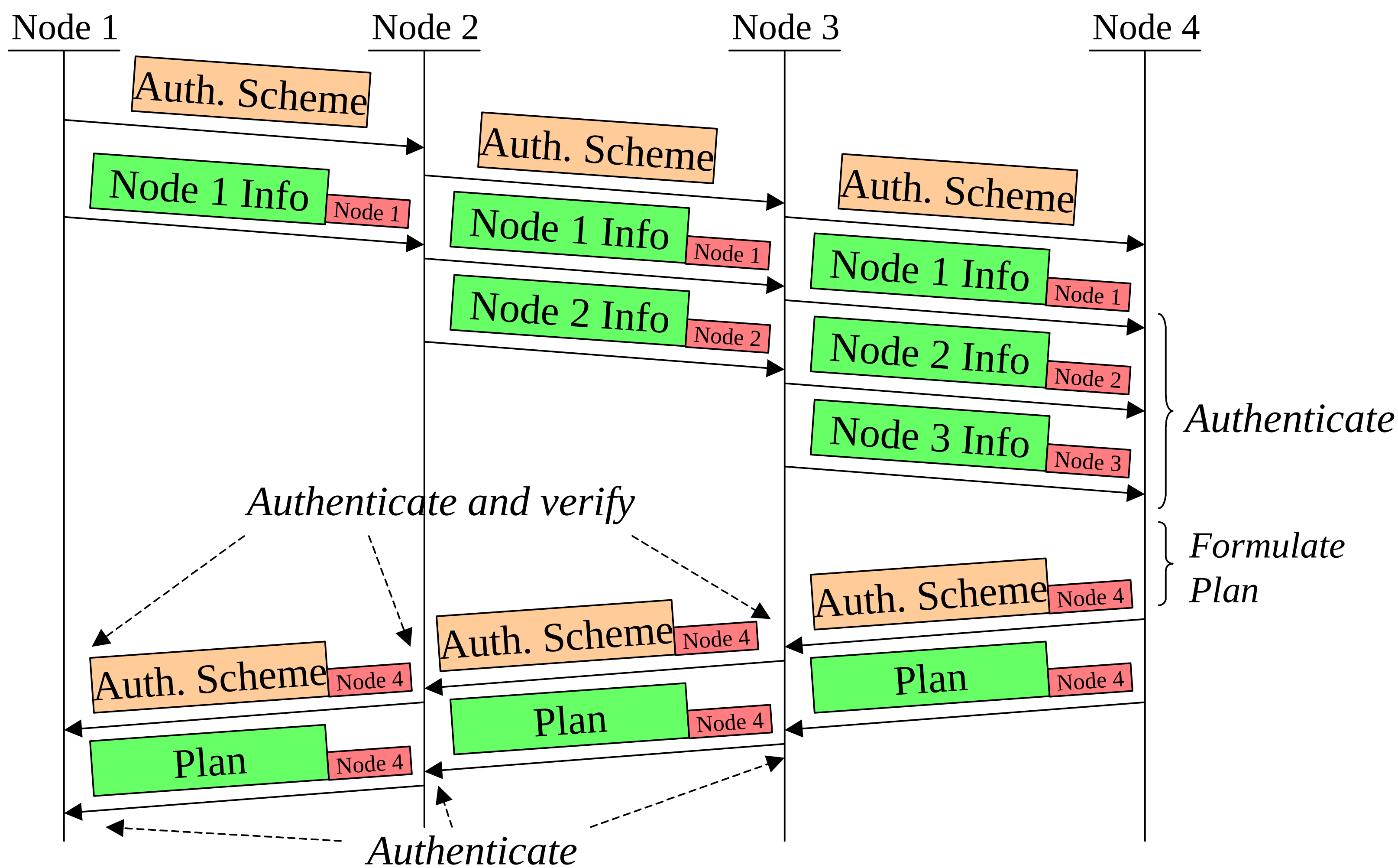
Securing Distributed Adaptation

- Goals:
  - Maintain endpoint control over adaptor selection and deployment
  - Protect user data
- Key difficulties
  - Cross-domain node participation
  - No ubiquitous authentication mechanism
  - Varying user requirements

Security in Conductor

- Solutions:
  - Security monitor controls planning messages
    - Messages can be authenticated
    - Dynamically pluggable authentication scheme
      - Selected at an endpoint
    - How do we ensure everyone uses the same authentication scheme?
  - Encryption adaptors protect user data
    - Still need secure key distribution

Security in Conductor



Security in Conductor

- Authentication schemes
  - None
  - Public key encryption
    - Hierarchical key service
    - Chain of trust
  - Kerberos
- Key distribution
  - Based on authentication scheme

Implementation Status

- Stream management
  - Interception based on port number
  - Routing based on underlying routing
- Reliability
  - Semantic segmentation: implemented
    - Adaptor API
  - Recovery protocol: partially implemented

Implementation Status

- Planning
  - Information gathering protocol: implemented
  - Simple planner and environment monitor
- Security
  - Security architecture: implemented
  - Several authentication mechanisms
  - Sample encryption adaptors: implemented

Implementation Status

- Completing the implementation
  - Suite of useful adaptors
  - Dynamic "plan formulation" algorithm
  - Complete implementation of the recovery algorithm

Measurement of Success

- Effectiveness
  - Construct examples similar to case studies
- Low overhead
  - Measure overheads when adaptation is not required
- Complete services
  - Dynamic demo: automatically deploy, respond to drastic changes, cope with failure

Measurement of Success

- Usability
  - Everyday use in a heterogeneous office environment

Schedule

2000	*Sep*	Initial Office Deployment	
	Oct		» Adaptor suite
	Nov	Development:	» Dynamic planning
	Dec		» Recovery protocol
2001	*Jan*	Dynamic Demo	
	Feb	Measurements	
	Mar		
	Apr	Dissertation	
	May		

Contributions of This Work

- Design: architecture to make distributed adaptation possible
- Technical: new model and algorithms for reliability in the face of adaptation
  - Semantic Segmentation
- Engineering: a deployable system
- Demonstration: fully application-unaware adaptation is feasible

Conclusions

- In heterogeneous networks distributed adaptation enables graceful degradation
- Conductor enables distributed adaptation
  - First design and implementation of distributed adaptation
  - Reliability model compatible with adaptation
  - Architecture for coordinated adaptation
  - Trusted coordination for disjoint nodes