Automated Planning for Open Network Architectures

Alexey Rudenko

Advisors: Peter Reiher and Gerald J. Popek

University of California, Los Angeles

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Introduction

- Motivation
  - Distributed adaptations can improve often-poor QoS
  - How to perform adapter distribution?
  - Automated solution is preferred
- Goal
  - Allocate adapters for a connection
  - Under various constraints
- Challenge
  - Build a planning system that can be used transparently for applications in programmable networks

Accomplishments

- Designed and implemented an automated planning system that calculates and deploys plans
- Measured the performance of the planning system
- Demonstrated advantages of planning
- Results are being published

Reasons for Adaptability

- Network variability
  - Bandwidth, latency, jitter, security, reliability, monetary cost
- Network heterogeneity
  - Internet, wireless, dial-up, specialized client devices
- Some applications require at least a particular level of service
  - Real-time applications

Adaptations

- Application data stream can be adapted with:
  - Compression
  - Distilling
  - Encryption
  - Prioritization
  - Data storage (caching, prefetching, buffering)
  - Scheduling wireless interface
  - FEC

Open Network Architectures

- Programmable networks whose behavior can be dynamically changed
  - User data adaptation
  - User data rerouting
- Active Networks, Conductor
  - Dynamic deployment of adapters

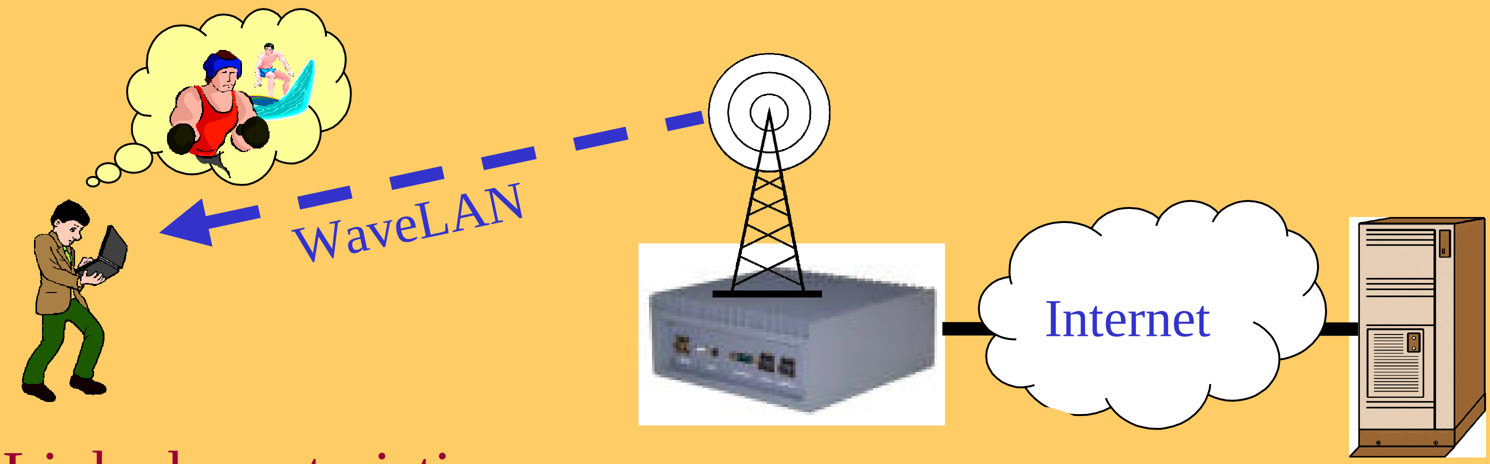
Planned Distributed Adaptation

- Select and distribute adapters within programmable networks to effectively improve QoS of applications
- Build automated planning system for unicast connections serving adaptation-unaware applications

Plan is a set of instructions to the connection nodes

- what adapter to use
- in what order
- with respect to available node resources

Secure Low-Bandwidth Web



Link characteristics:

Low bandwidth
Insecure
Unreliable

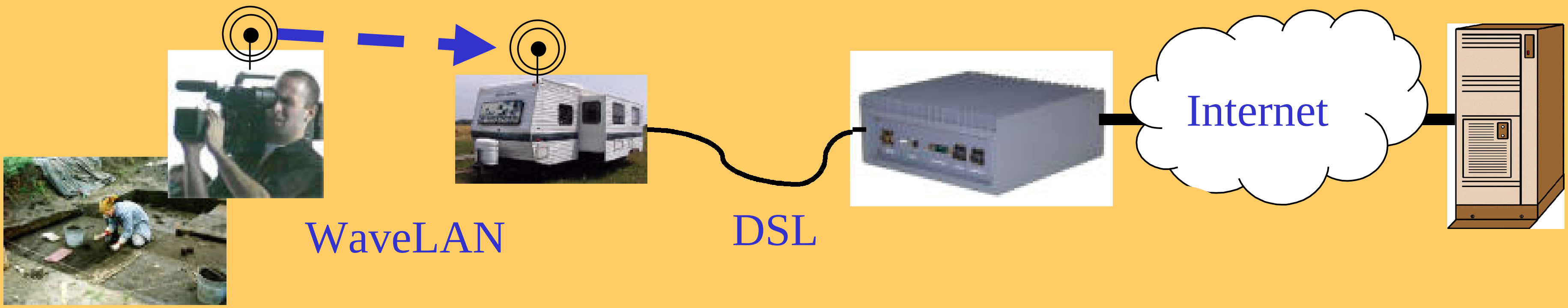
Insecure

Adaptation:

Prioritizing
Compression
Encryption
FEC

Encryption

Secure Low-Bandwidth Video



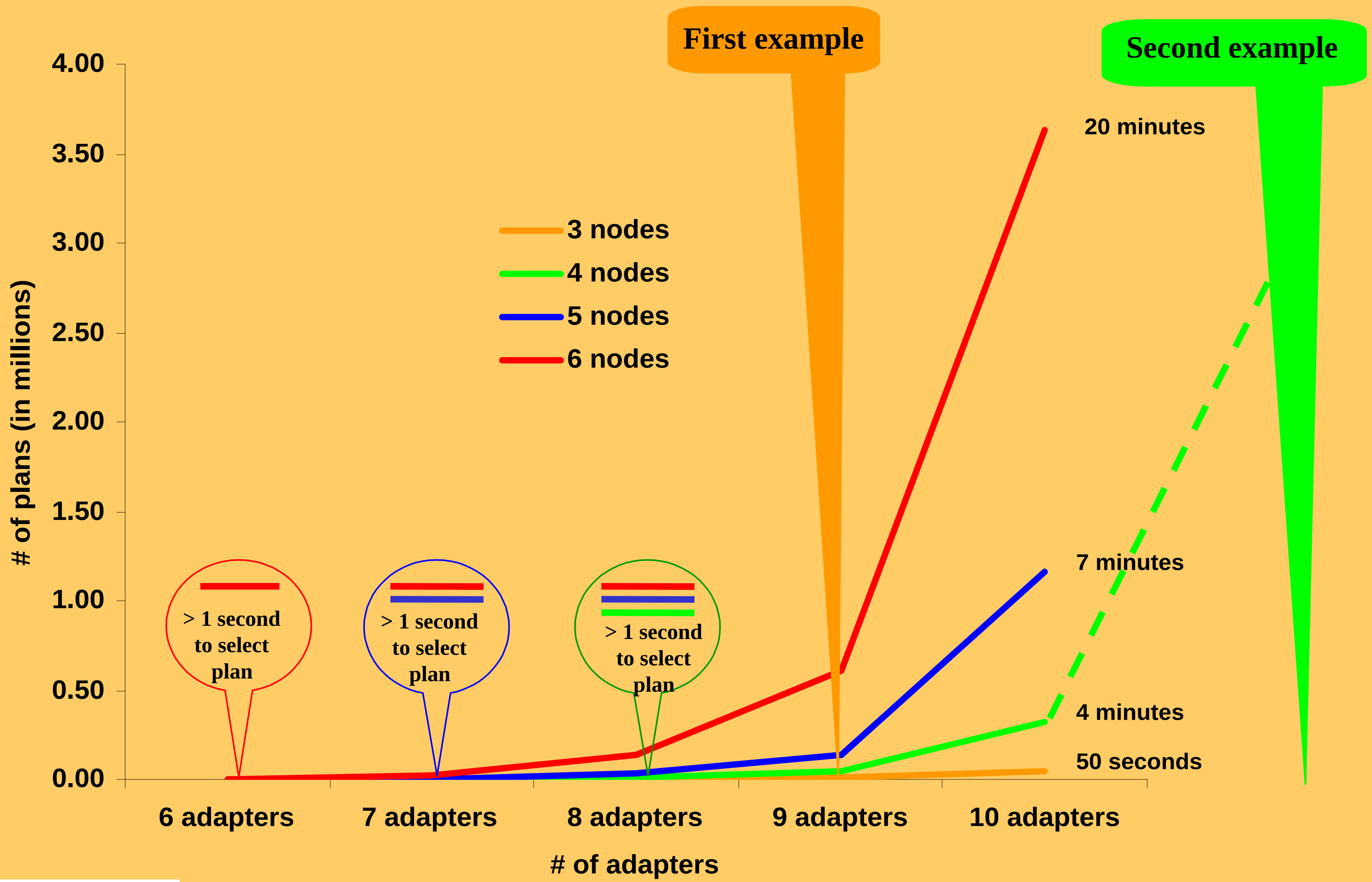
Link characteristics:

Low bandwidth Insecure Unreliable	Low bandwidth	Insecure

Adaptation:

Compression Encryption FEC	Distilling Compression	Encryption

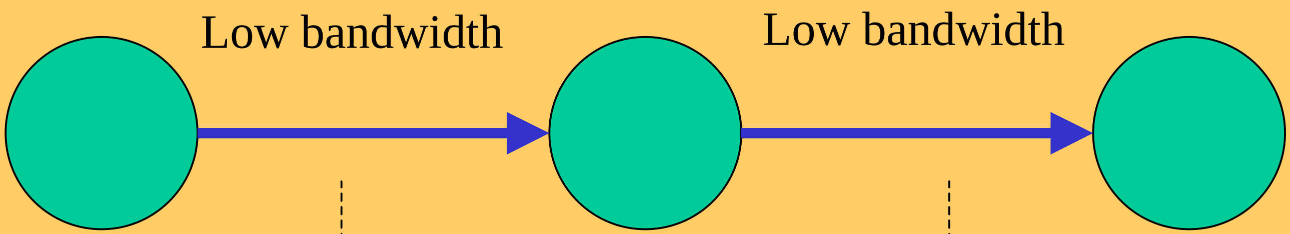
Exhaustive Search



Naïve Template Planning

- Adapters always on problematic links
- Example of an inefficient solution

Link characteristics:

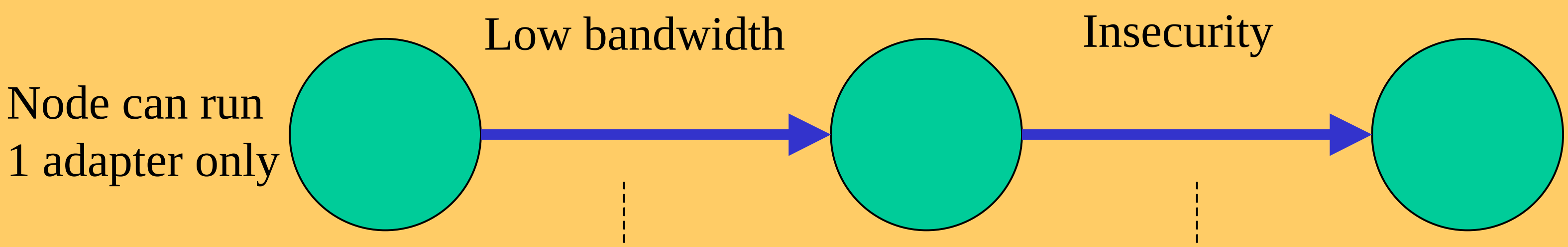


Naïve solution: Compress	Decompress Compress	Decompress
Optimal solution: Compress		Decompress

Naïve Template Planning 2

- Adapters always on end links
- Example of an infeasible solution

Link characteristics:



	Node 1	Node 2	Node 3
Naïve solution:	Compress Encrypt		Decrypt Decompress
Only solution:	Compress	Decompress Encrypt	Decrypt

Full-Scale Template Planning

- Exponential space of network situations is referred to a smaller number of precalculated plan templates
- Put real adapters during connection establishment
- Potentially inefficient, infeasible

Solution: Online Automated Planning

- Allocate adapters
- Satisfy constraints
  - Keep used link resources below offered limits
  - Keep used node resource below offered limits
  - Minimize nodes' resources used

Requirements to Planning

- Planning must be fast to benefit real-time applications
- Adapters must be consistent
  - No adapter inhibits the work of another adapter
  - Semantics of data is preserved
- Adapters must be efficiently selected, ordered, and located

Requirements (cont.)

- Extensibility of the system
  - Independent evolution of planners and adapters
- Resource management
  - Accept or reject a new connection
  - Stop, kill, or replan old connections
- Security of the planning procedure
- Fault-tolerance (what if node/adapter fails?)
- Accounting

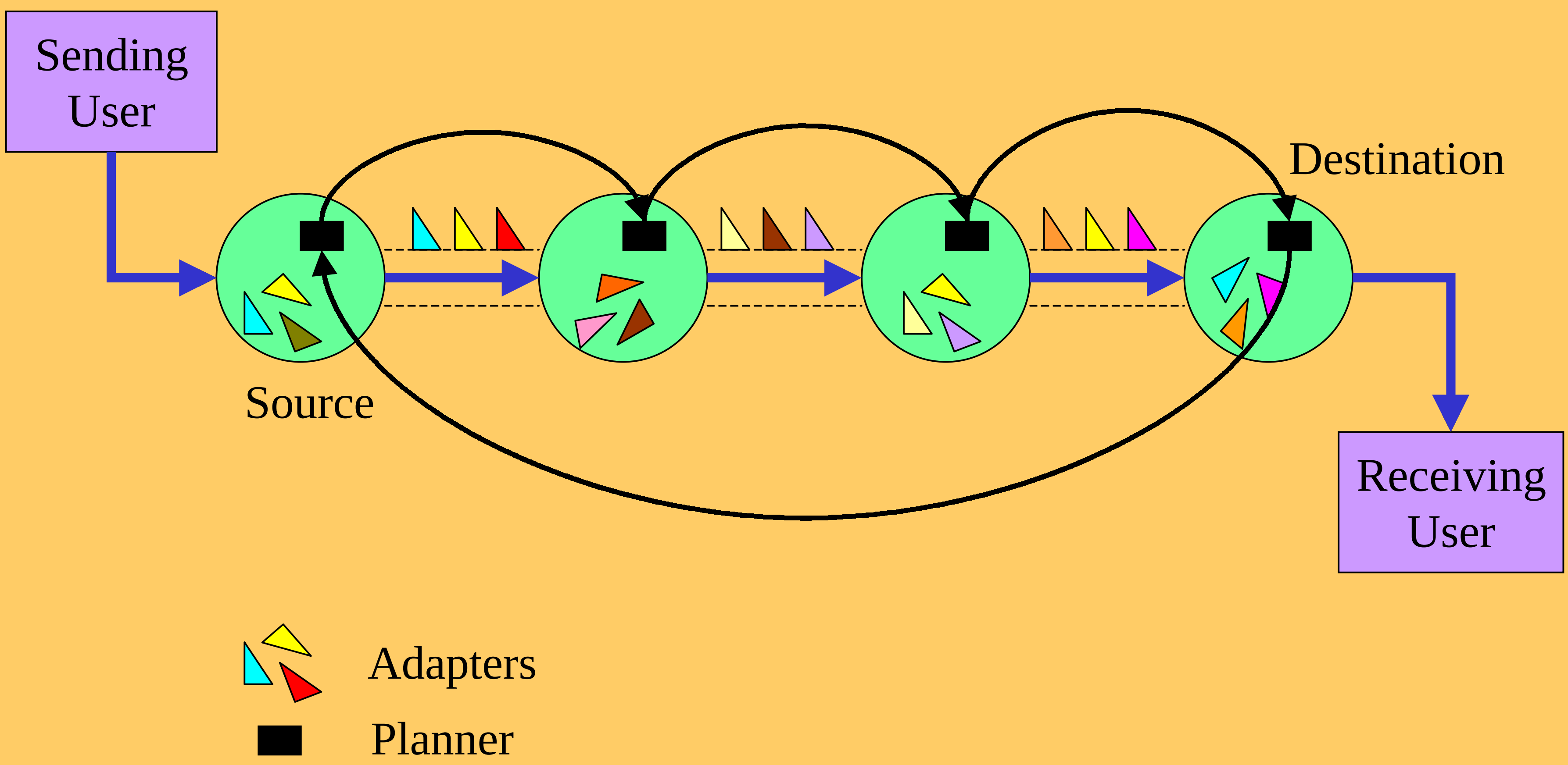
General Planning Procedure

- Planning data collection
  - User preferences
  - Application data stream requirements
  - Network conditions
- Plan calculation with the planning algorithm
- Plan deployment
- Local planning and centralized planning

Local Planning

- Local plan between two neighbor nodes
  - Assume
    - planning data collected off-line
    - adapters are locally available
  - Local planning: adapter selection and ordering
- Chain of sequential local plans
  - Can be used as a solution
  - Calculated fast
  - Potentially inefficient

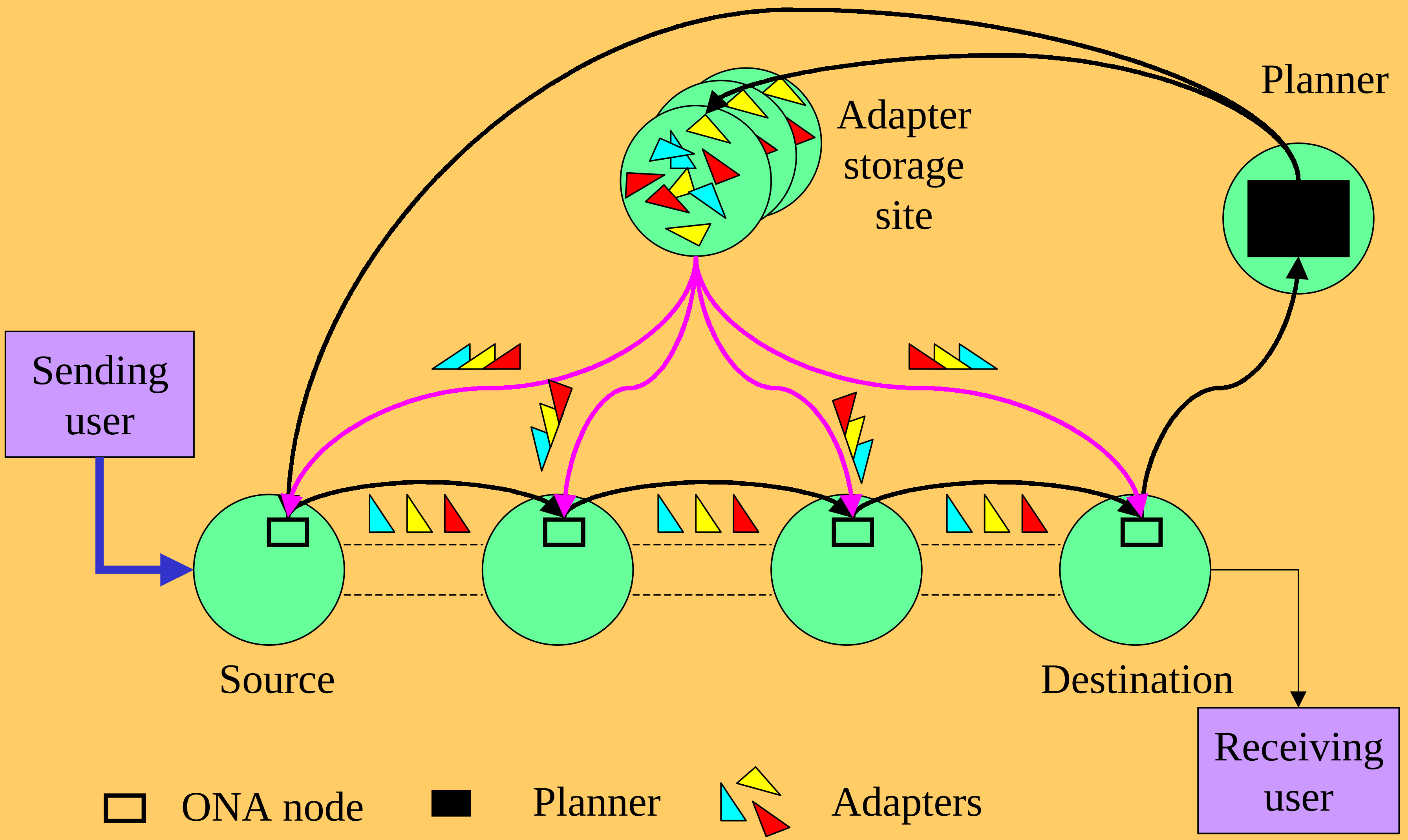
Local Planning



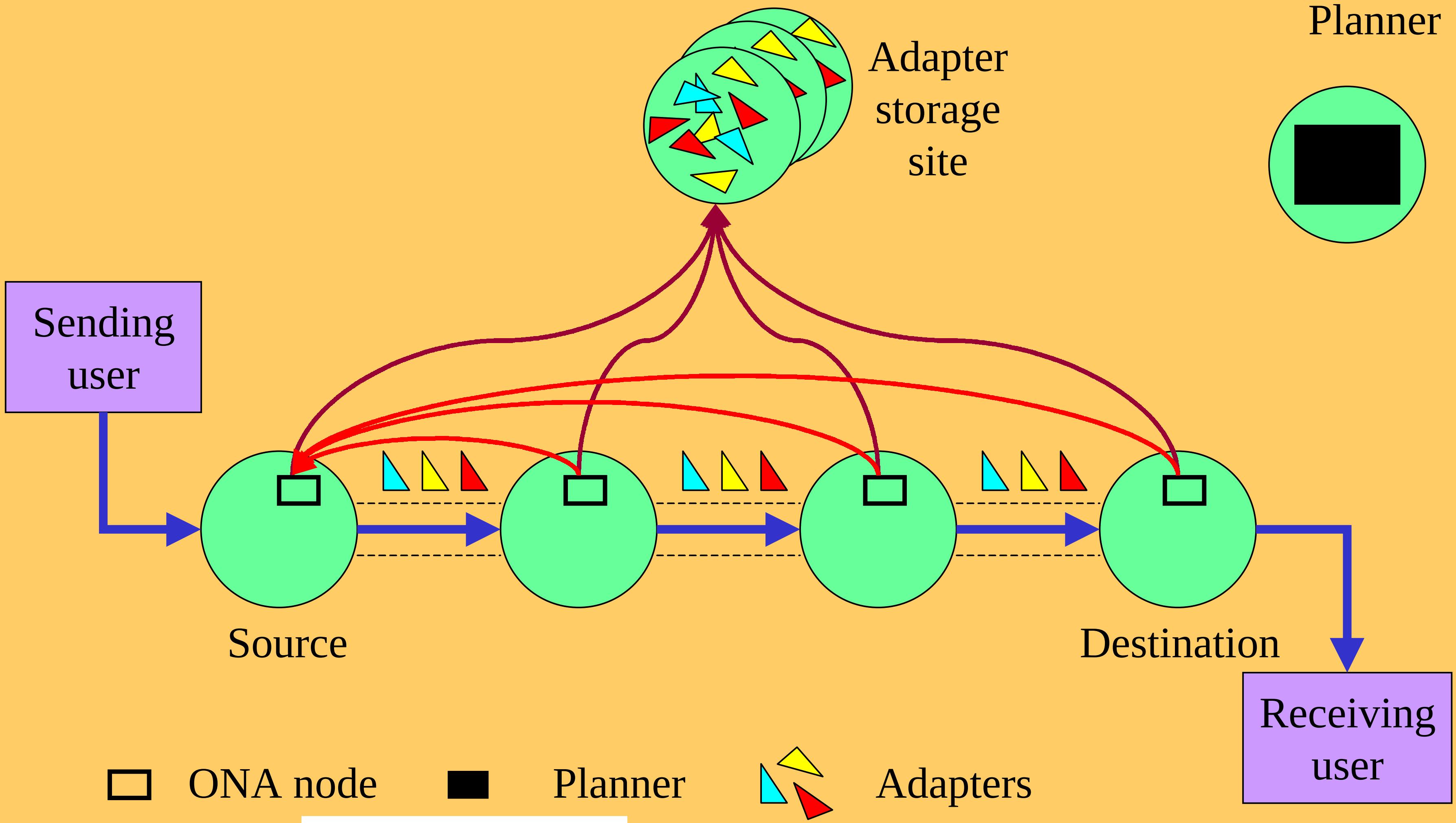
Centralized Planning

- Collects planning data about a connection
  - Application requirements
  - Network conditions
- Calculates a plan
- Deploys the plan
- More efficient but harder to calculate

Centralized Planning (cont.)

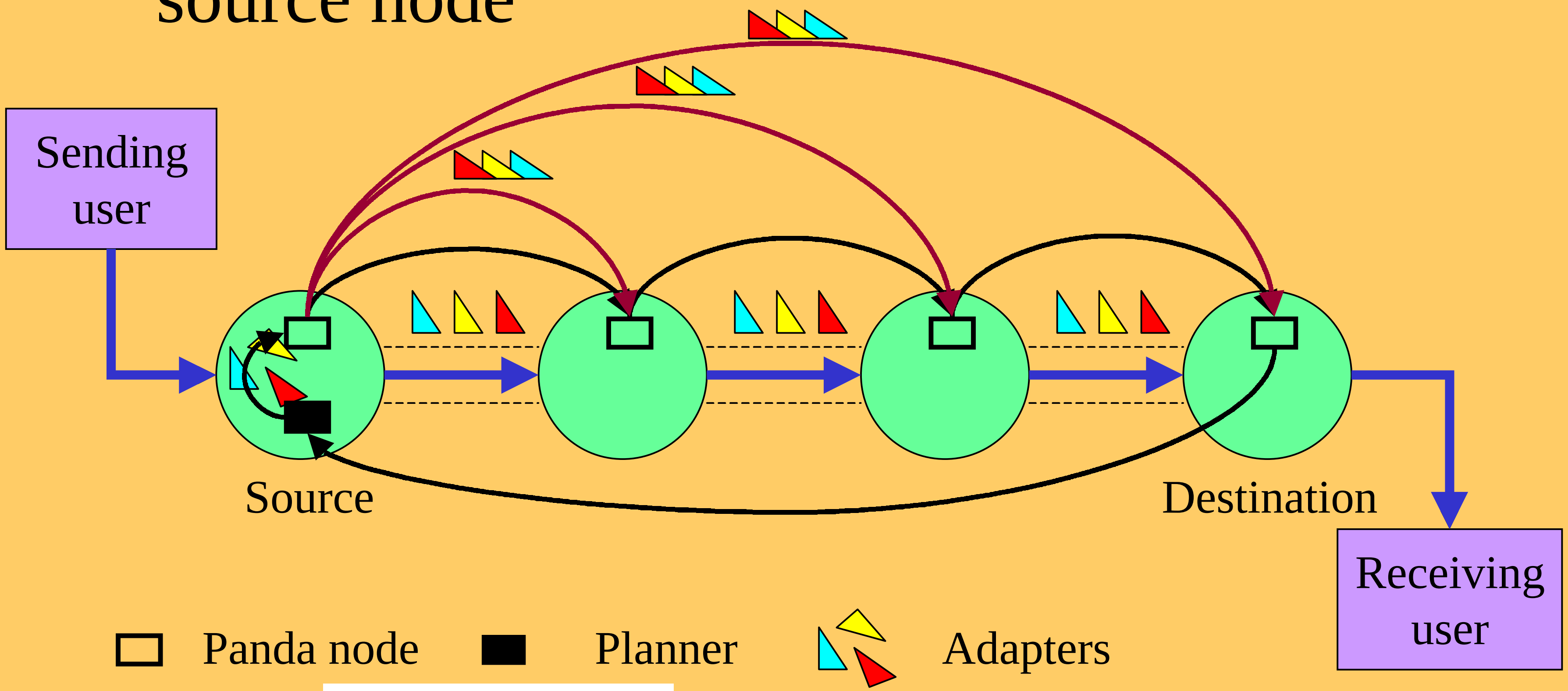


Centralized Planning (cont.)



Implementation with Panda

- Panda AN system designed in our lab
- Planner and adapter storage site on the source node



Combined Planning Procedure

- Local planning is first
- Switch to a new central plan when it is ready
  - Central plan may not be necessary for short (< 100 packets) connections
  - Factors for longer life of local plan
    - slow machines
    - busy network
    - central plan calculation delay or failure
    - central plan deployment delay or failure

Combined Planning Procedure

- Network conditions can change during session
  - Run centralized planning again
  - Switch to a new central plan

- Now: how to calculate a plan?

Planning Algorithm

- Planner must understand adapter data

Adapter data structure

Problem ID	Solution method
Effects: Efficiency of solution, impact on data size, lossless (y/n), etc.	
Costs: Required executional resources, execution latency, monetary cost, delivery latency, etc.	
Preconditions	Postconditions

Example of compressor data

Low bandwidth	LZ compression
Effects: efficiency = 0.5 data size coefficient = 0.5 lossless = yes	
Costs: CPU, memory, HD	
Compressability = 1	**Compressability = 0**

Planning Data

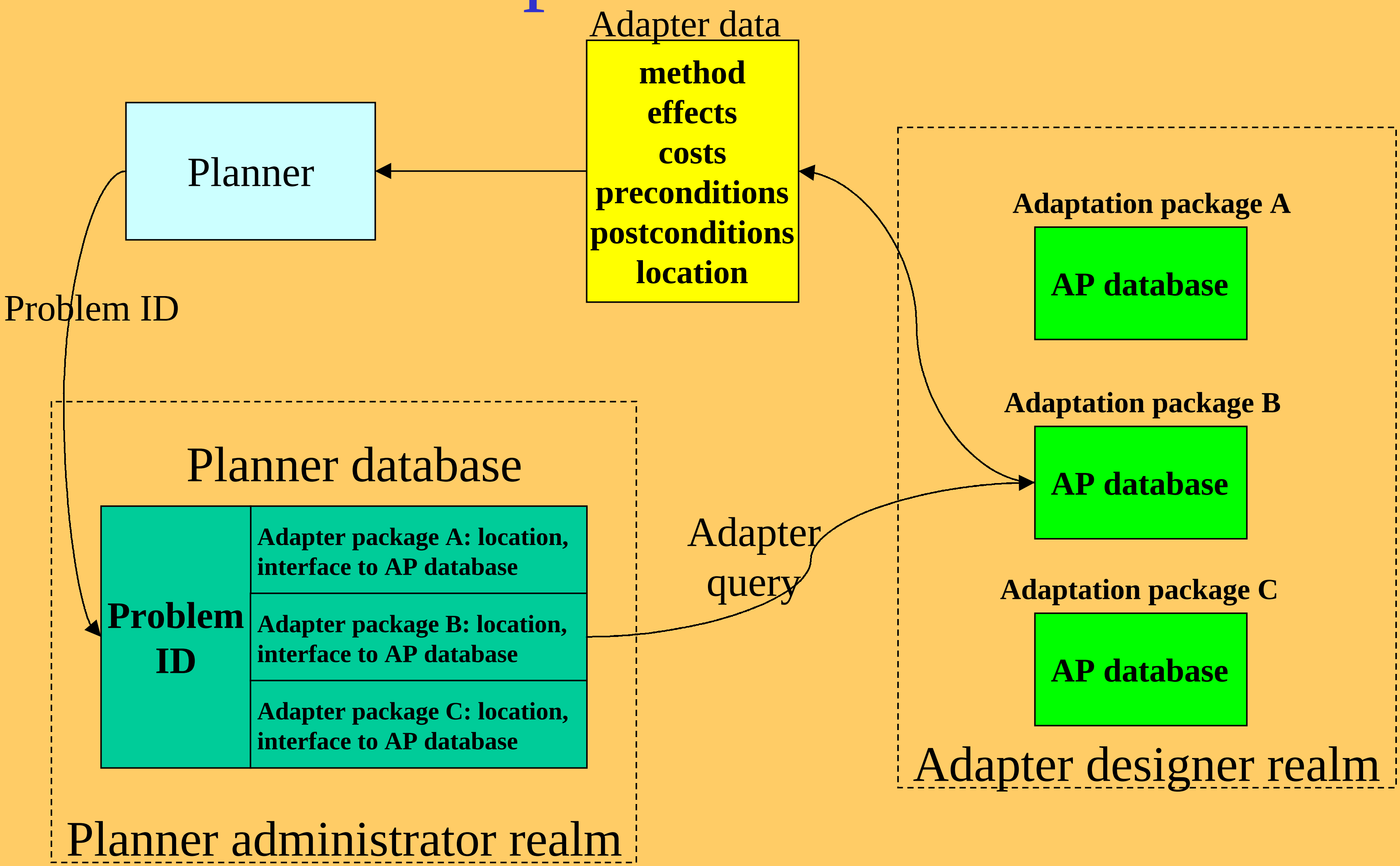
- What data is necessary for planning?

Category	Attributes (example)
Stream characteristics	Throughput, format, encrypted (y/n), compressed (y/n)
Stream requirements	Throughput, secret (y/n)
User preferences	User chooses a solution method if more than one exists
Link resources	Bandwidth, secure (y/n), reliable (y/n), etc.
Node resources	CPU, memory, HD

Heuristic Search in Plan Space

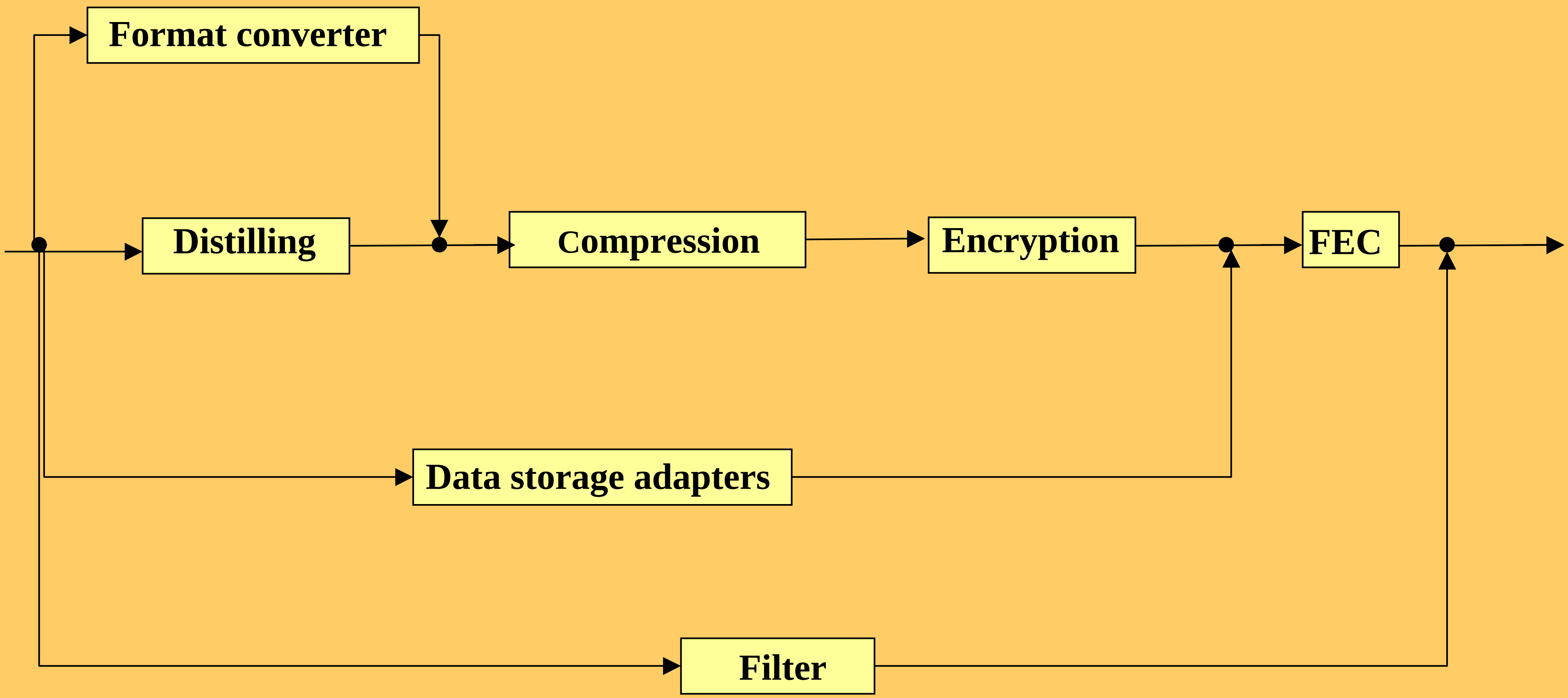
- Run sequentially
  - Adapter selection
    - using real adapters, handle plan feasibility and adapter consistency from the beginning of a planning process
  - Adapter ordering
    - templates can be calculated off-line
  - Optimize of adapter locations in the results of adapter selection and ordering

Adapter Selection



Adapter Ordering

- One or more partial-order plans ordered by solution methods



Adapter Ordering (cont.)

- Additional constraints come from:
  - Application-level protocol requirements
  - Adapter preconditions/postconditions
    - e.g., adapter requires a particular format
  - Network conditions
    - if users are not able to decrypt cached data, it should be cached unencrypted

Adapter Ordering (cont.)

- Conflicts between real adapters during ordering
  - Detected through precondition and postcondition analysis
  - Resolved through
    - reorder, if partial order plan allows
    - adding more adapters
  - If not solvable, adapter selection must be repeated

Resulting Local Plans

- Result of adapter selection and ordering
  - Chain of local per-link plans
  - The result plan works
  - But can be inefficient
    - processes data longer
    - wastes connection link resources

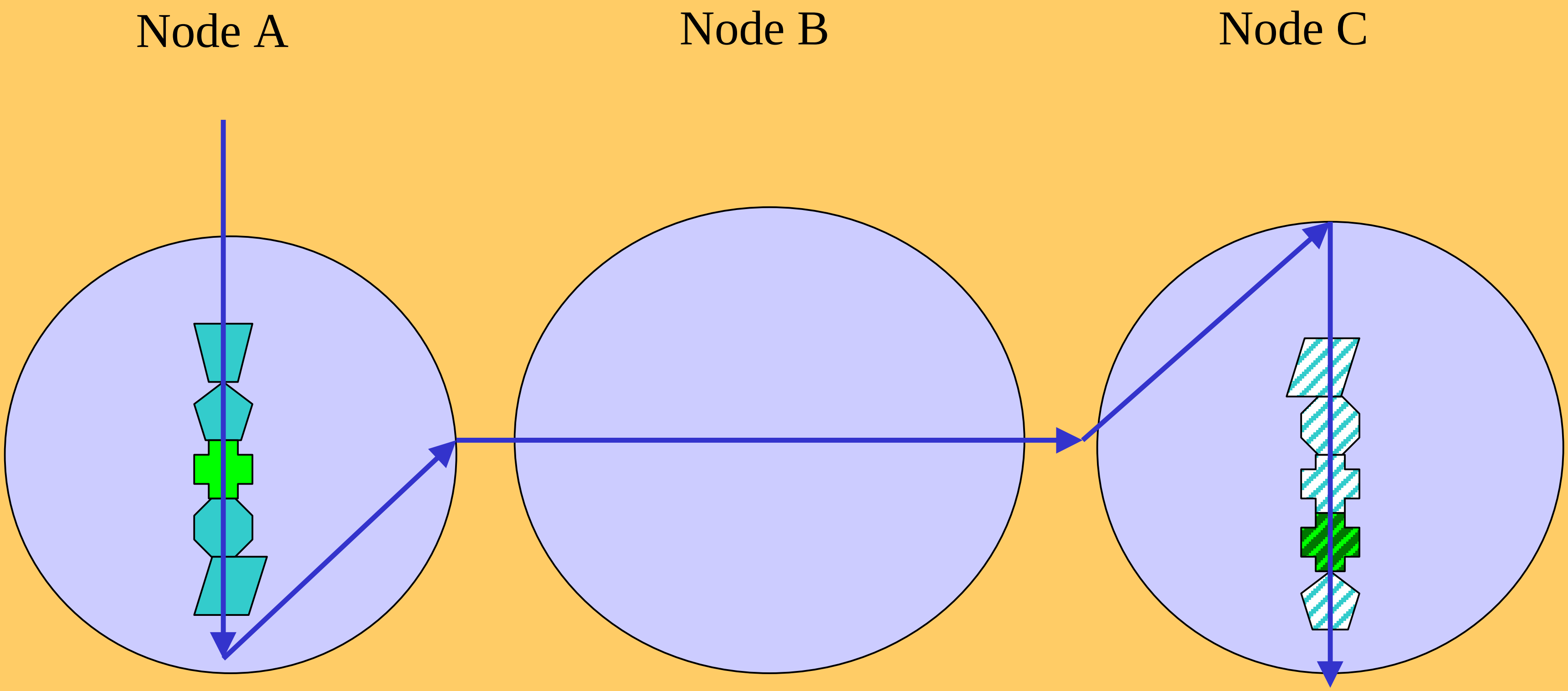
Optimization of Plan

- Optimization is needed
  - Cover more connection hops with an adapter that improves link conditions (compression, encryption, etc.)
    - Not with FEC, wireless interface scheduler, and some other adapters!
  - Drop redundant adapters
    - also reduce the latency of adaptation
  - Stay feasible

Plan Optimization

- Recursive best-first search
  - Local plan chain is the initial point
  - Transformation: merging neighboring plans
    - preserving adapter order
  - Evaluation function $f = \sum_{links} \sum_{k}^{link\ resources} \alpha_k lr_k + \sum_{nodes} \sum_{m}^{node\ resources} \beta_m nr_m$
    - α_k, β_m - weight coefficients
    - lr_k, nr_m - link and node resources
  - Find minimum of the function
    - can be local

Example of Two Plans Merging



Plan Merging (cont.)

- Plan merge can fail
  - discouraged by an evaluation function
  - insufficient knowledge about adapters
  - unrecoverable constraint conflict
  - insufficient computational resources on connection nodes
  - time limit
- Best-effort plan is delivered

Example of Planning

Link characteristics:

Low bandwidth Insecure Unreliable	Low bandwidth	Insecure

Source

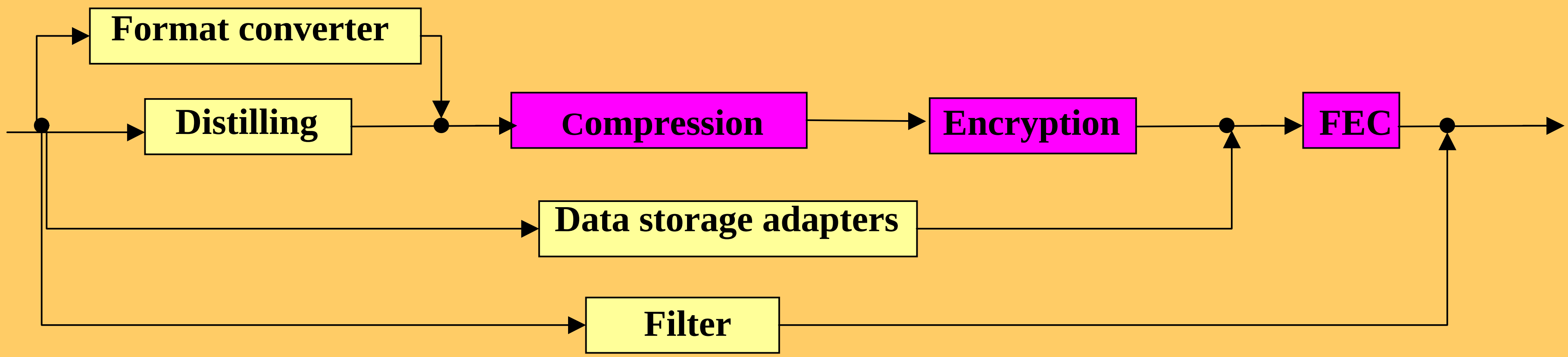
Destination

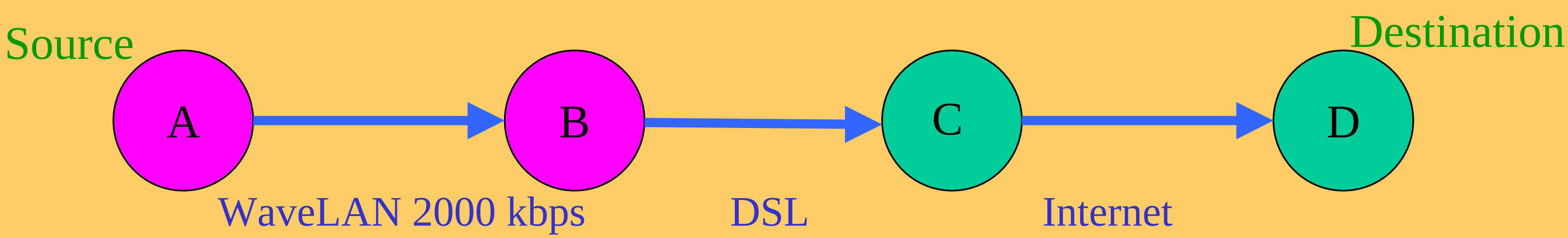
WaveLAN 2000 kbps	DSL	Internet

Adaptation:

Compression Encryption FEC	Distilling Compression	Encryption

Example of Planning





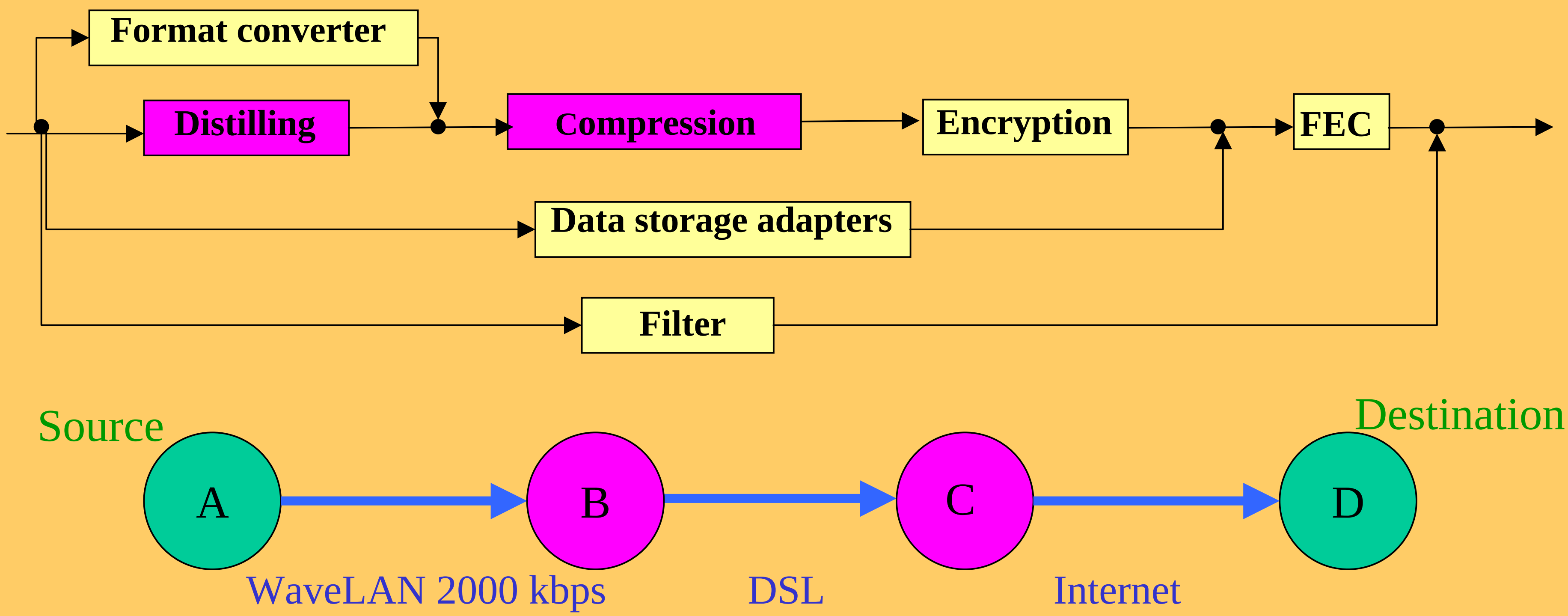
Adaptation:

Compression
Encryption
FEC

Distilling
Compression

Encryption

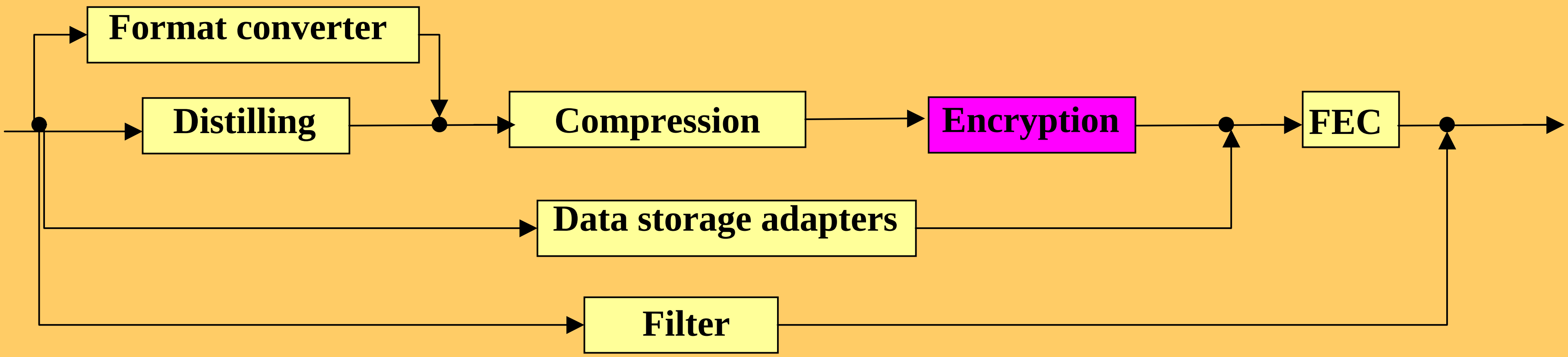
Example of Planning (cont.)

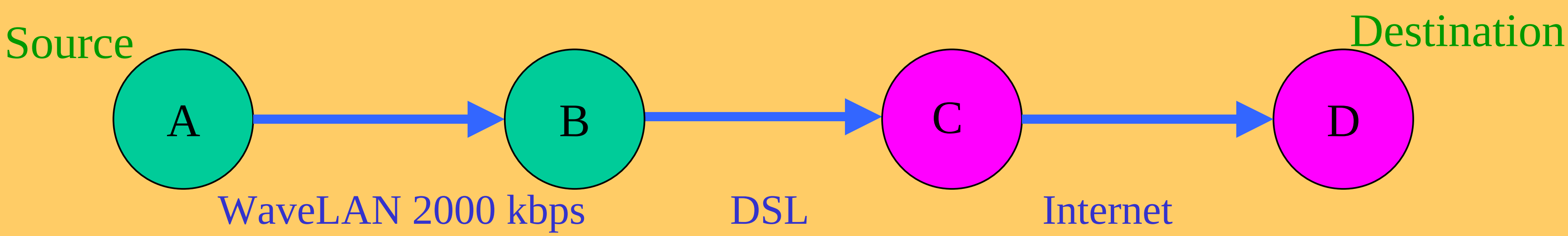


Adaptation:

Compression Encryption FEC	Distilling Compression	Encryption

Example of Planning (cont.)



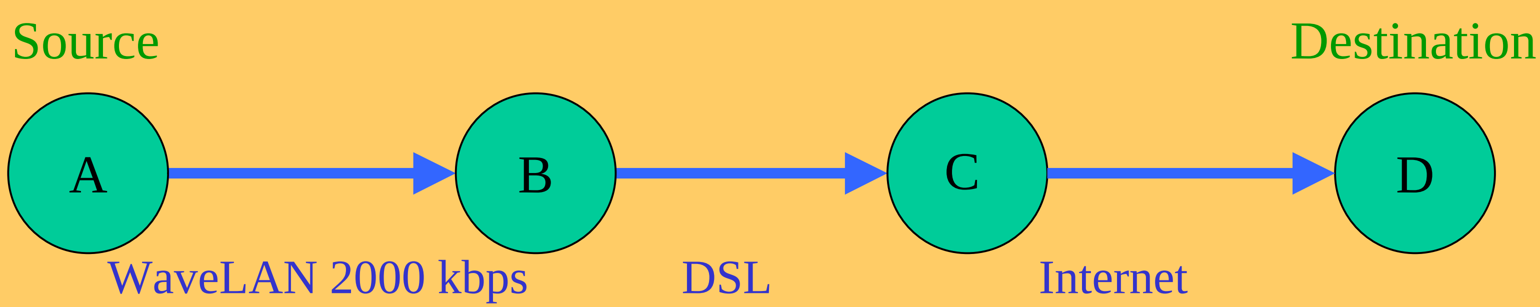


Adaptation:

Compression Encryption FEC	Distilling Compression	Encryption

Example (cont.)

- Chain of local plans

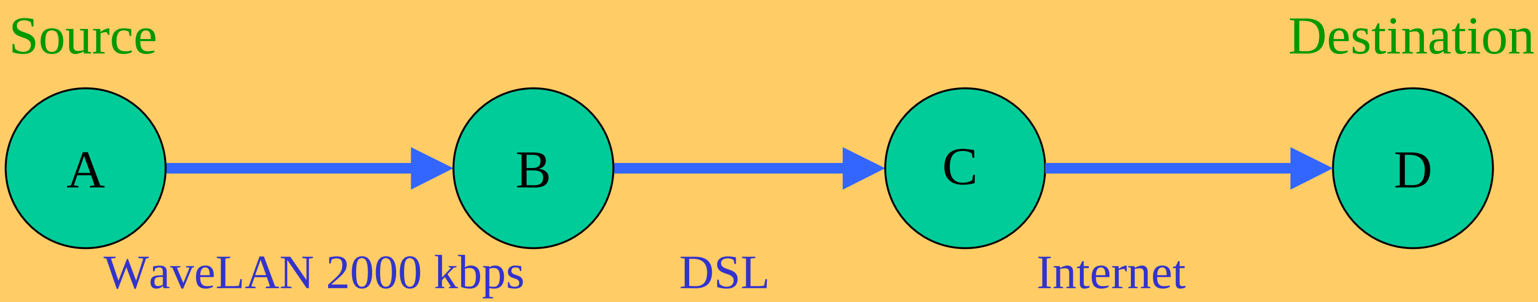


Adapters:

Compressor	DeFEC	Decompressor	Decryptor
Encryptor	Decryptor	Encryptor	
FEC	Decompressor		
	Resolution Drop		
	Compressor		

Example (cont.)

- Merge AB+BC
  - DeFEC stays on B
  - Compression dropped

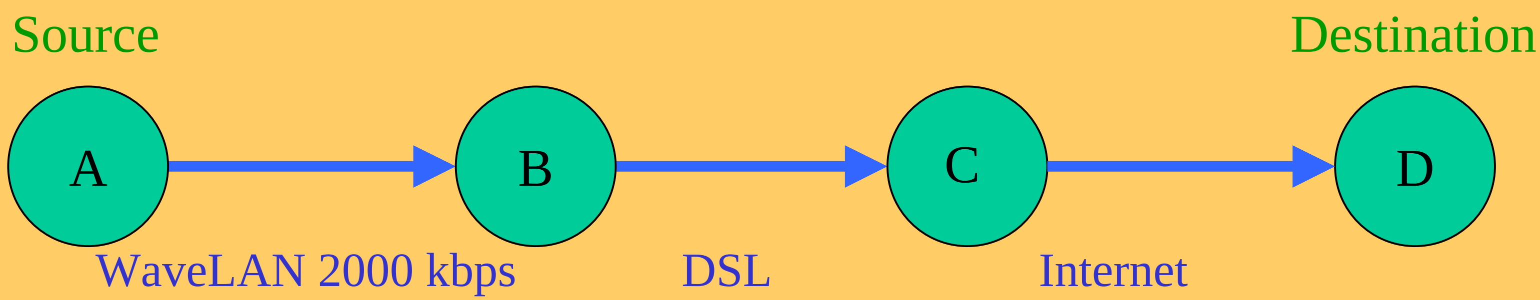


Adapters:

Resolution Drop	DeFEC	Decryptor	Decryptor
Compressor		~~Decompressor~~	
~~Compressor~~		Decompressor	
Encryptor		Encryptor	
FEC			

Example (cont.)

- Merge AC + CD
  - Encryption dropped



Adapters:

Resolution Drop
Compressor
~~Encryptor~~
Encryptor
FEC

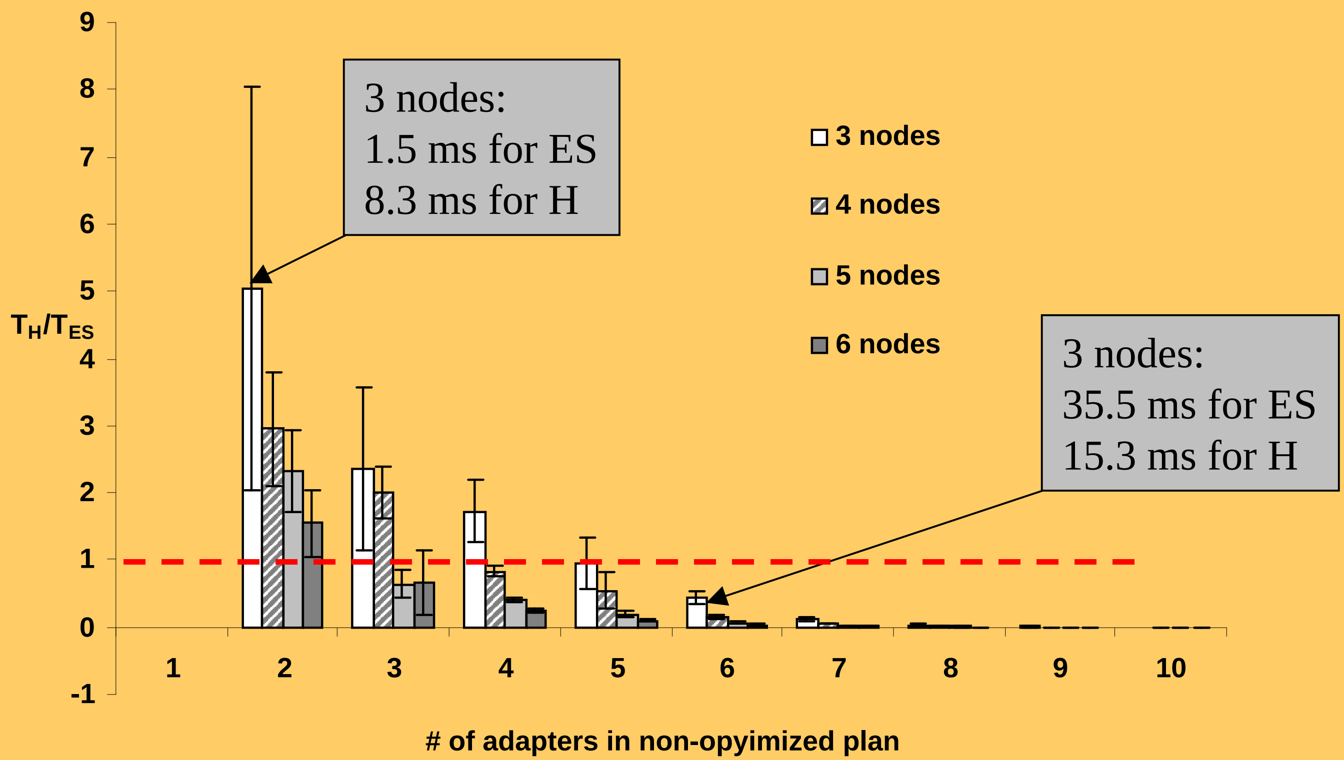
DeFEC

~~Decryptor~~
Decryptor
Decompressor

Performance Results

- The planner testing on a separate machine
  - Dell Inspiron, 333 MHz, 128MB
  - Simulate connections
    - number of nodes (2 to 15)
    - problems of low bandwidth, very low bandwidth, and security for each link
    - number of adapters a node can execute (1 to 10)
  - Exhaustive search planner for heuristics search evaluation

Heuristics/Exhaustive Planning Latency Ratio



Given that an optimal plan exists, it was not found in:

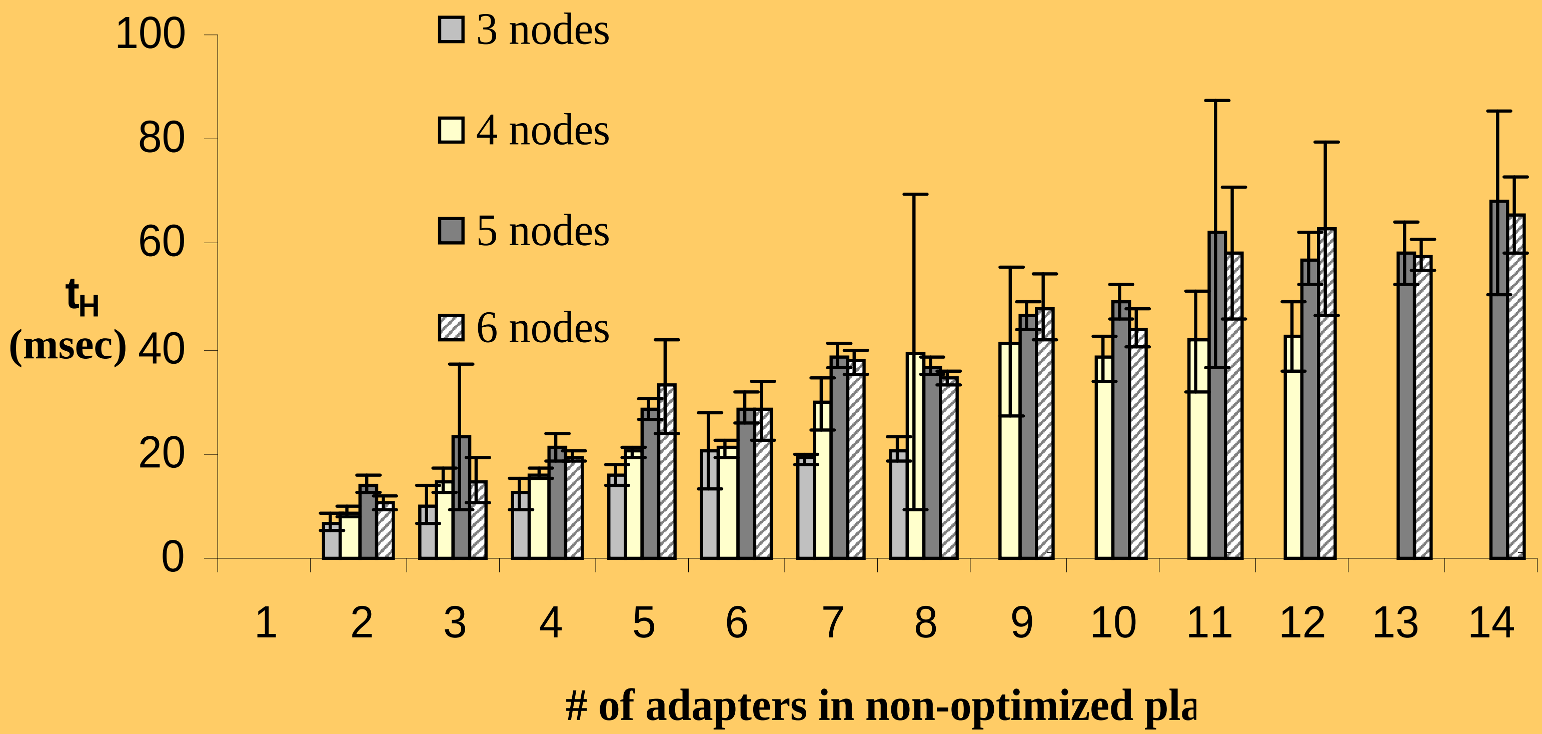
1 case for 4-node connection (from 1000 tries)

3 cases for 5-node connection (from 1000 tries)

8 cases for 6-node connection (occurred in about 1 percent of tries)

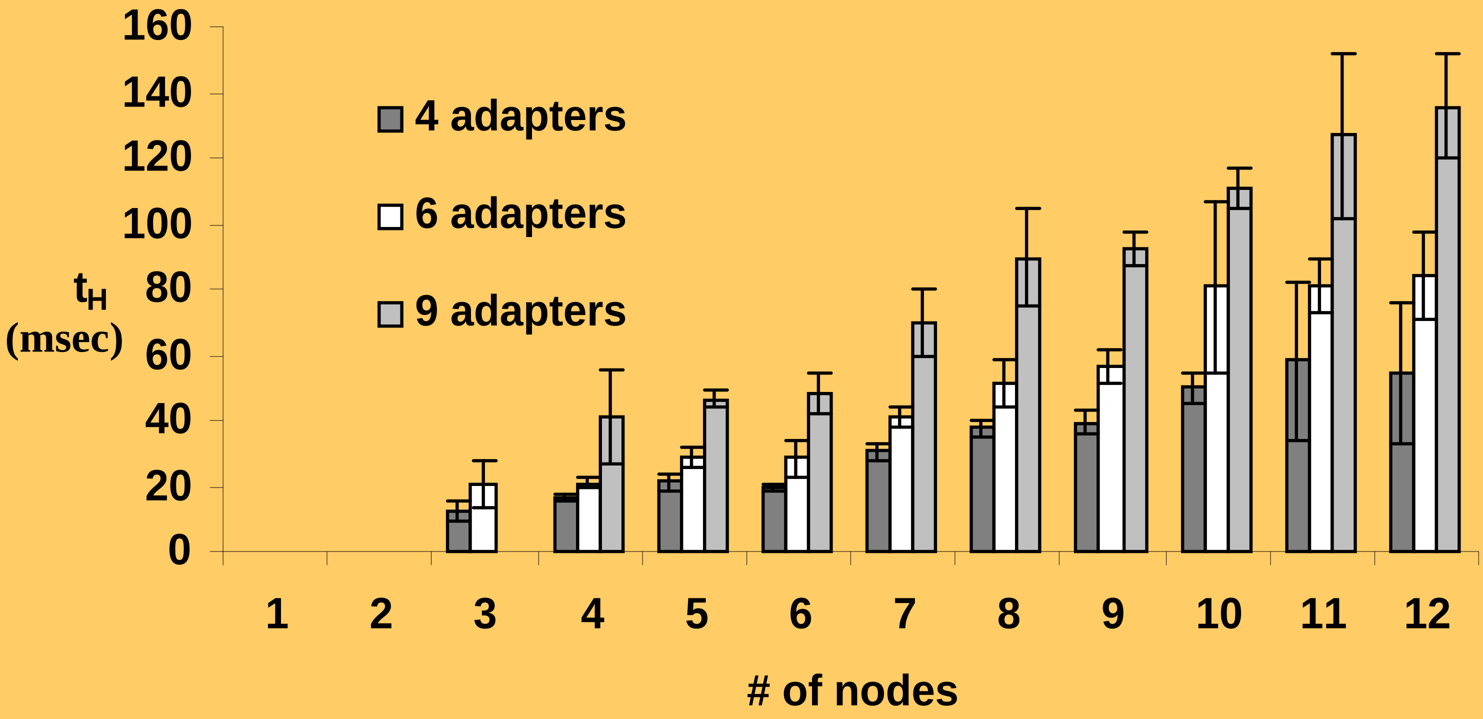
Planning Algorithm Test

6 nodes, 14 adapters: 90 milliseconds at most



Planning Algorithm Test (cont.)

12 nodes, 9 adapters: 160 milliseconds at most

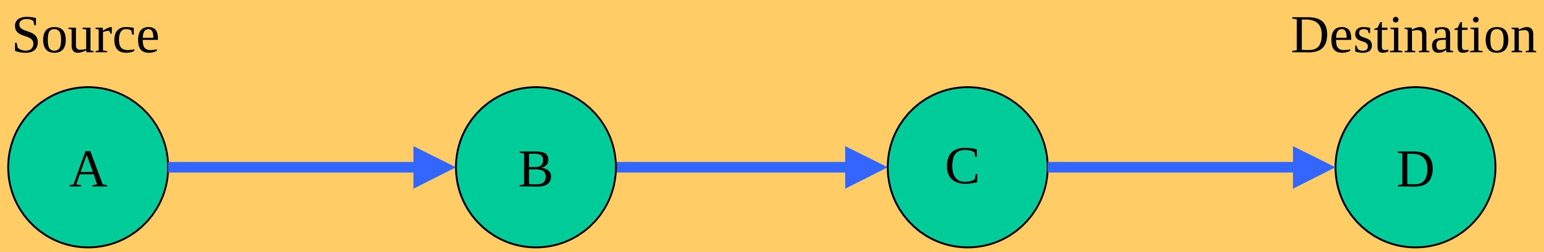


Real-time Application Test

- HP Omnibook, 500 MHz, 128Mb
- Panda middleware with planner
- Applications
  - Connector (test application)
  - WaveVideo multimedia package [Fankhauser99]
- Adapters
  - Null adapters, resolution-drop, encryption

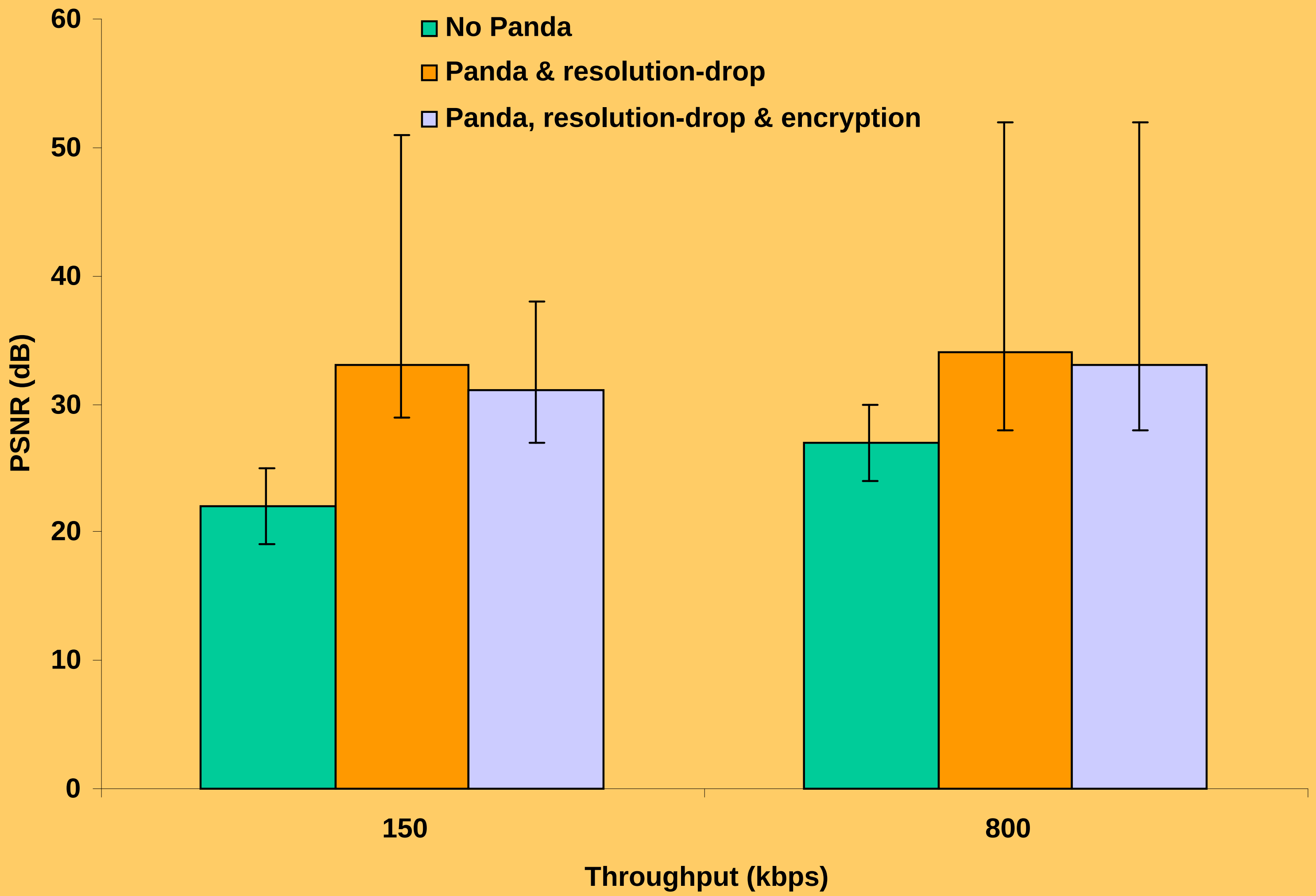
Application Test (cont.)

- 2-, 3-, 4-node connections
- Link conditions
  - 150 Kbps, 800 Kbps
  - secure, insecure
- QoS is measured in dB, peak signal-to-noise ratio (PSNR)



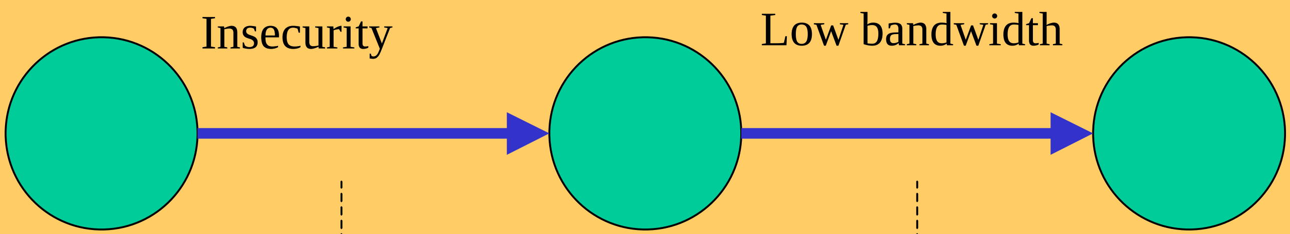
PSNR (luminance)

PSNR is 10 dB higher for an adapted stream



Centralized vs. Local Planning

Link characteristics:



Local plan:

Encrypt

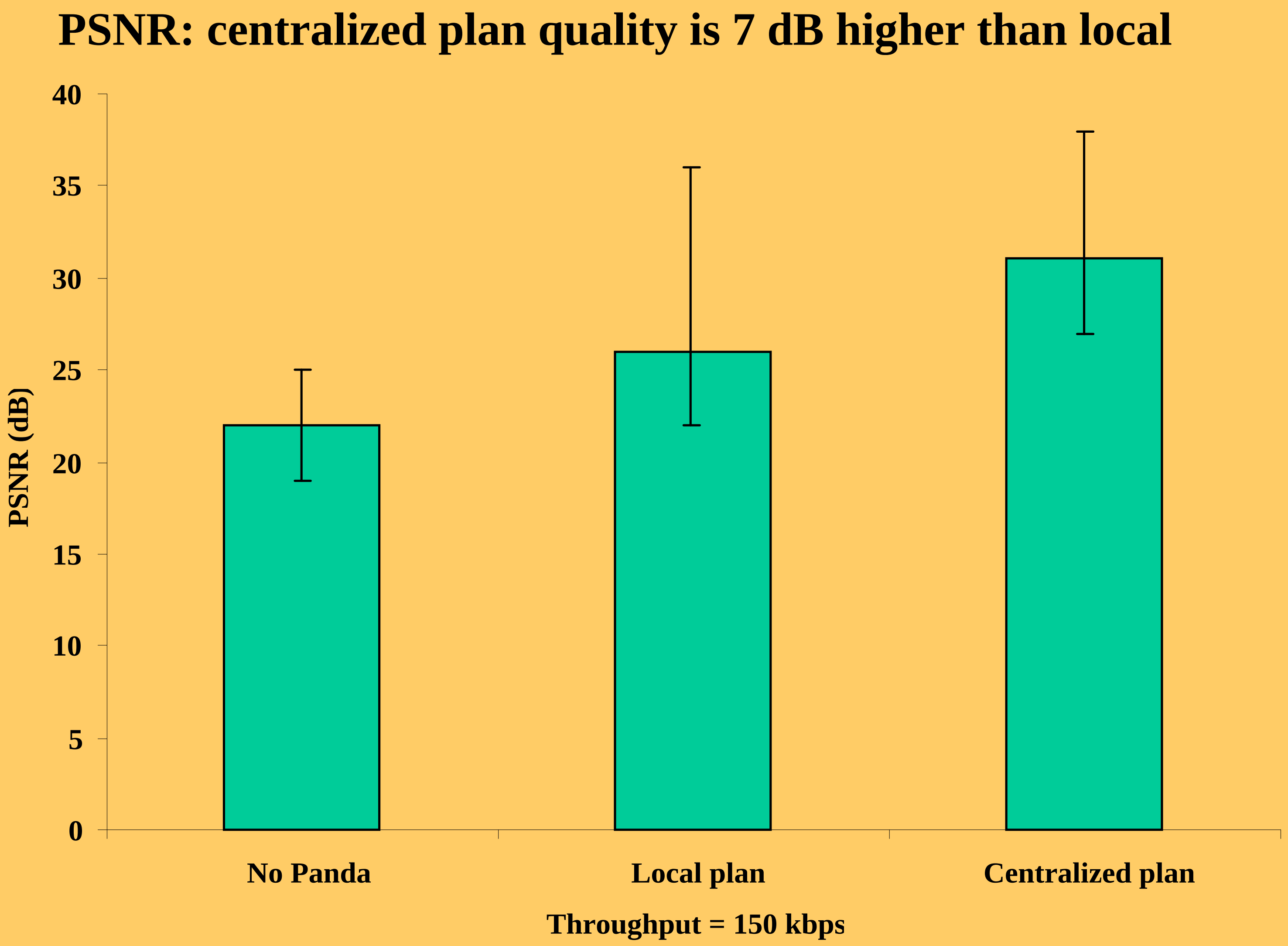
Decrypt
Distill

Centralized plan:

Distill
Encrypt

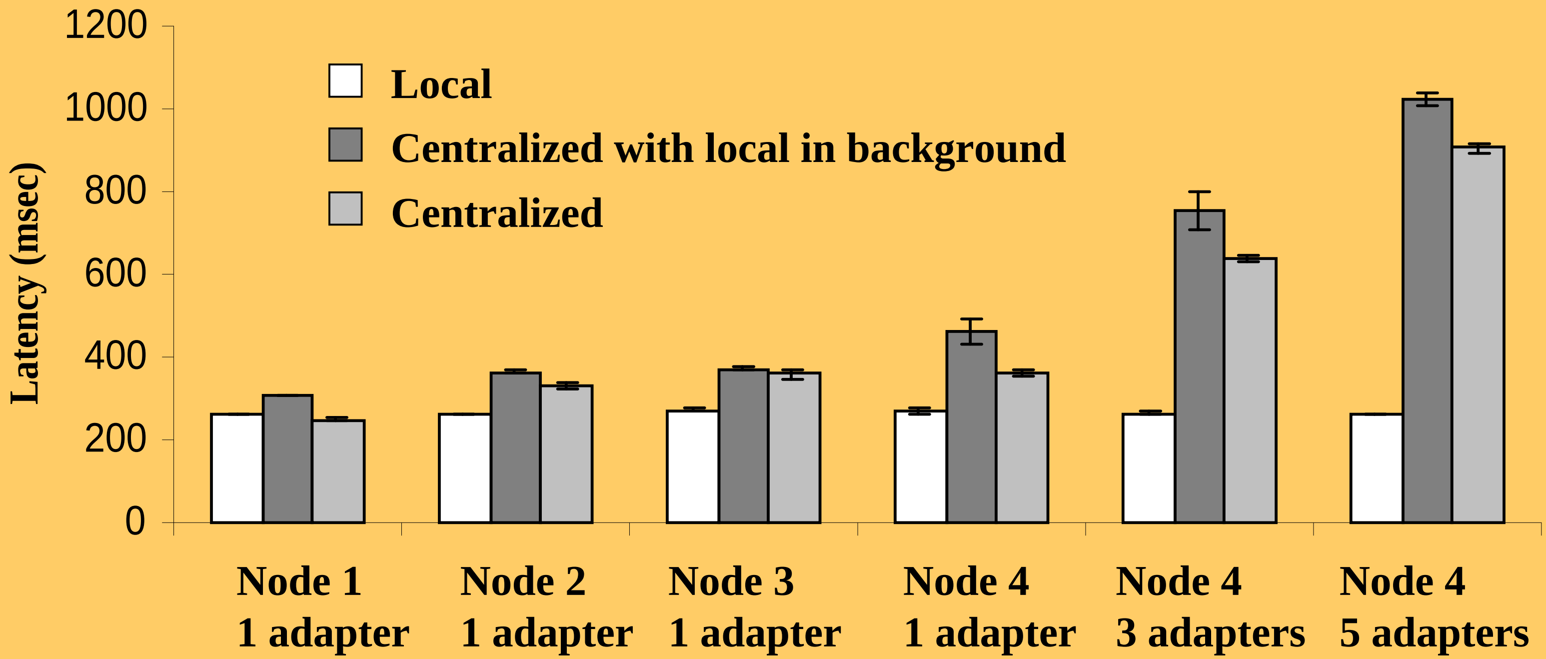
Decrypt

Centralized vs. Local Planning



Planning Procedure Latency

Planning procedure is 1.1 second at most
100 to150 packets under local plan before central plan is on



Related Work

- Naïve Planning (mostly proxies)
  – Agent-proxy Mowgli [Liuljeberg96]
- Template Planning
  – Conductor [Yarvis00]
- Online Planning
  – Adaptation: CANS [Fu01]
- Inspirational AI Planning Approaches
  – least-commitment planning [Kamphampati94]
  – RBFS [Korf93]

Contribution

- Designed and implemented
  - Heuristic planning algorithm for unicast connections
    - adapter data structure
    - adapter selection supporting system extensibility
    - adapter ordering
    - plan optimization
  - Feasible automated planning procedure
    - Combined local and centralized planning
    - Replanning
    - Shown that real-time applications benefit

Work was presented

- Demonstrations
  - DARPA site visit
  - UCLA CSD Annual Research Review
- Publications
  - Openarch 2000
  - Dance 2002
  - Other papers in the works

Wider Applicability

- Beneficial for rescue/military missions
  - Ad hoc networks with highly customized application protocols
- Applicable on various distributed systems
  - Open network architectures
  - Peer-to-peer networks
  - Remote code invocation systems

Conclusion

- Feasible planning system for unicast connections is implemented
- Real-time applications benefit
- The planning system allows relatively independent development of planner and adapters
- The planning system improves active network resource distribution

End