CCD: Efficient Customized Content Dissemination in Distributed Publish/Subscribe

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Customized content dissemination on distributed Pub/Sub (CCD)

- Motivation
- Problem definition and formulation
- CCD algorithm
- Heuristic CCD algorithm
- Experimental evaluation

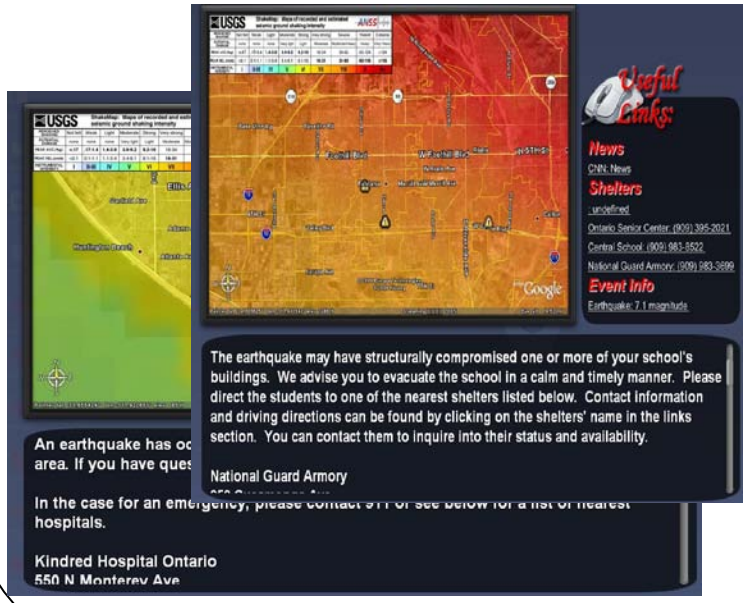
Domain: Emergency Notification Systems

One or a few generic messages sent to the entire impacted population

Under response

Over response

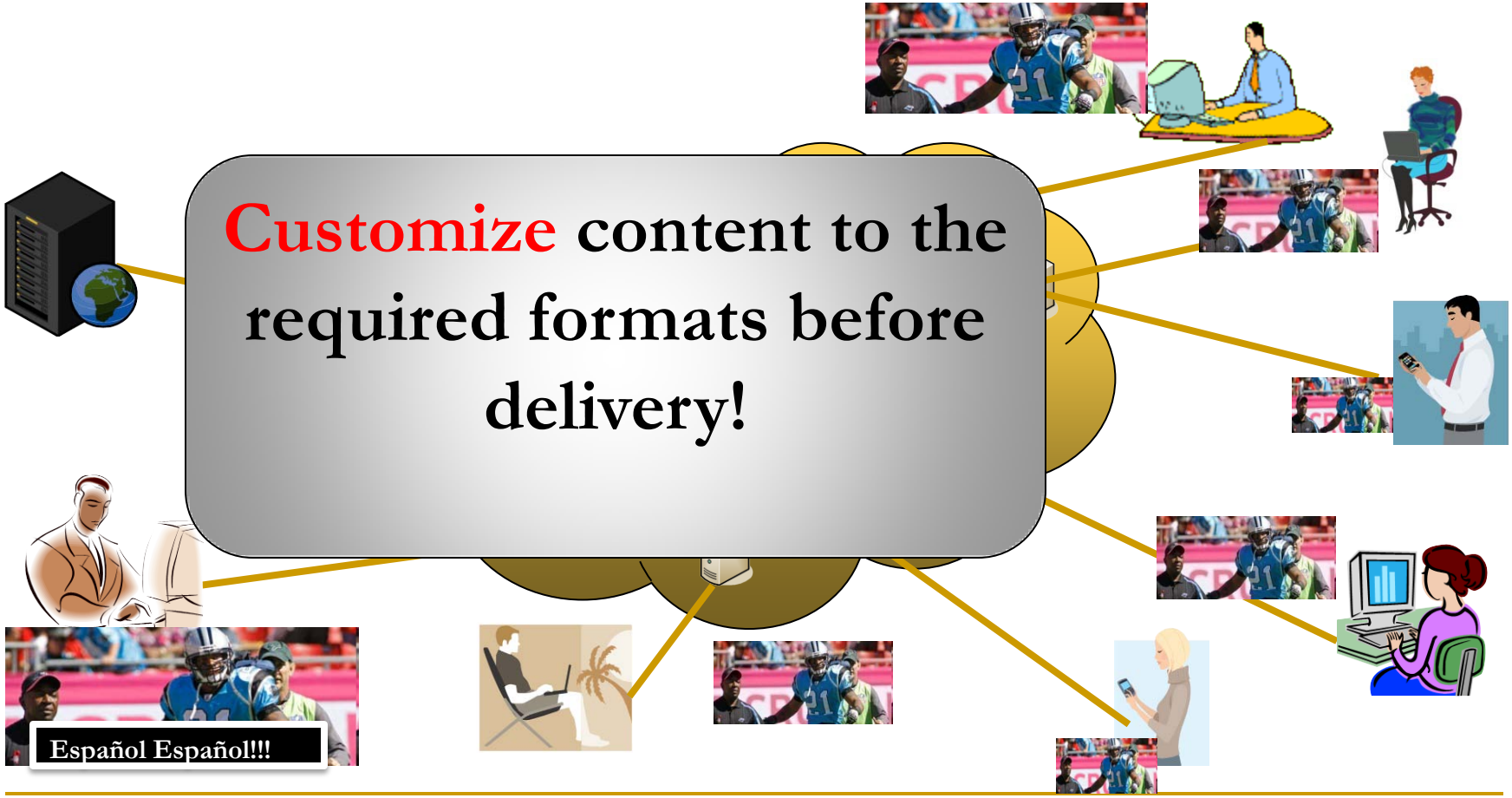
Goal: Customized Notifications are sent to the population using multiple modalities



Motivation

- Leveraging pub/sub framework for dissemination of rich content formats, e.g., multimedia content.

Customized delivery



Subscriptions in CCD

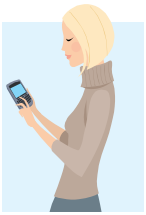
- How to specify required formats?
- Receiving context:
  - Receiving device capabilities
    - Display screen, available software,…
  - Communication capabilities
    - Available bandwidth
  - User profile
    - Location, language,…

Subscription:
- Team: USC
- Video: Touch Down

Context: PC, DSL, AVI

Subscription:
- Team: USC
- Video: Touch Down

Context: Phone, 3G, FLV



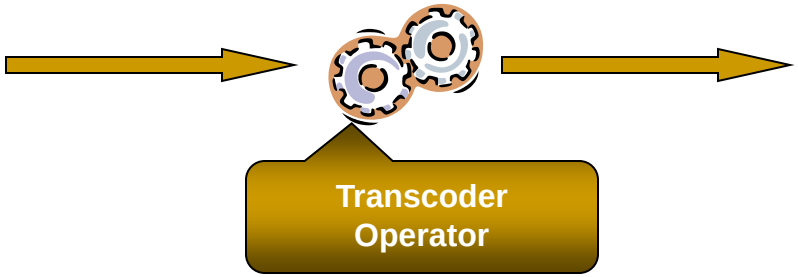
Subscription:
- Team: USC
- Video: Touch Down

Context: Laptop, 3G, AVI, Spanish subtitle

Content customization

- How is content customization done?
  - Adaptation operators

Original content
Size: 28MB



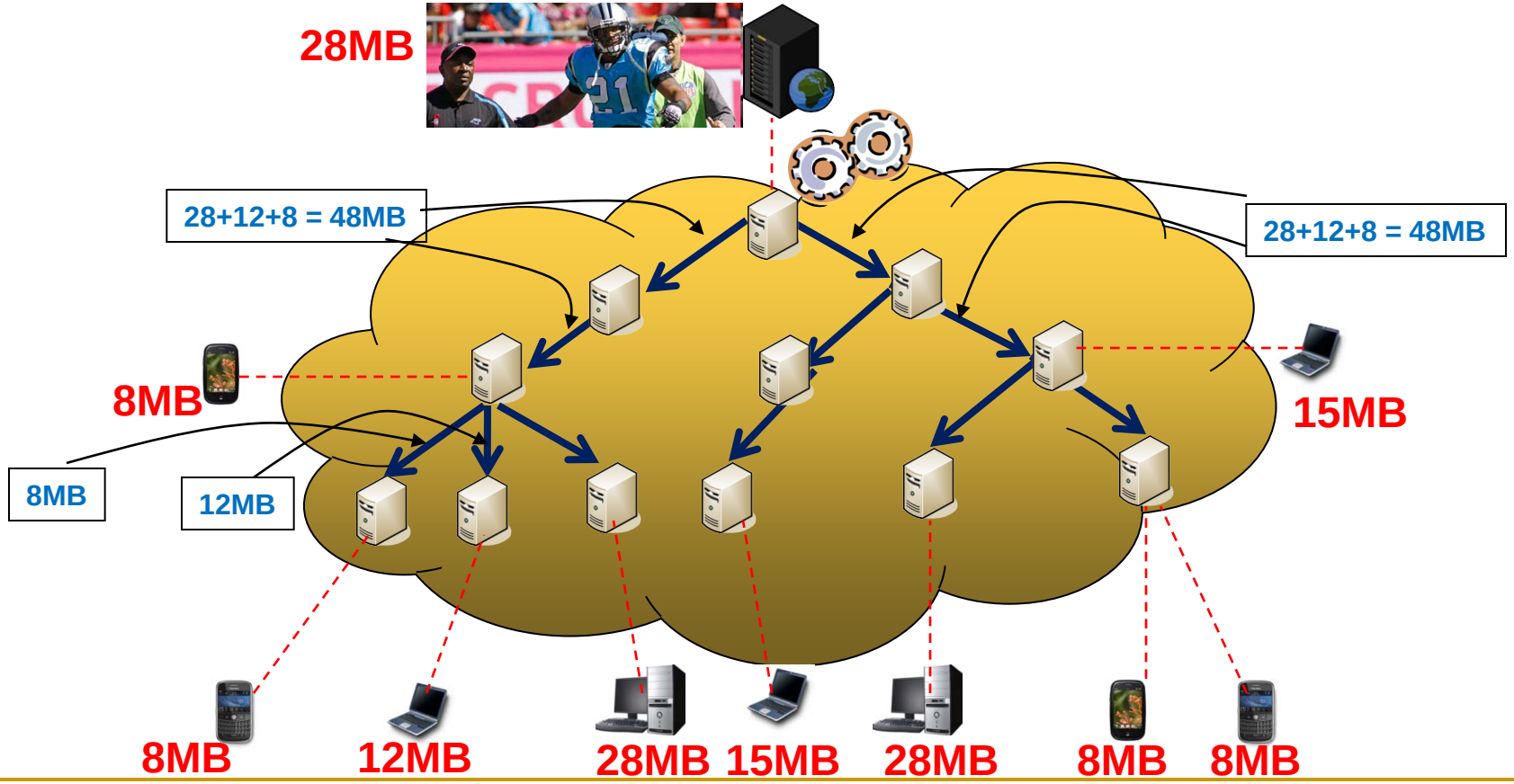
Low resolution and small content suitable for mobile clients
Size: 8MB

Challenges

- **How do we perform content customization in distributed pub/sub infrastructures?**

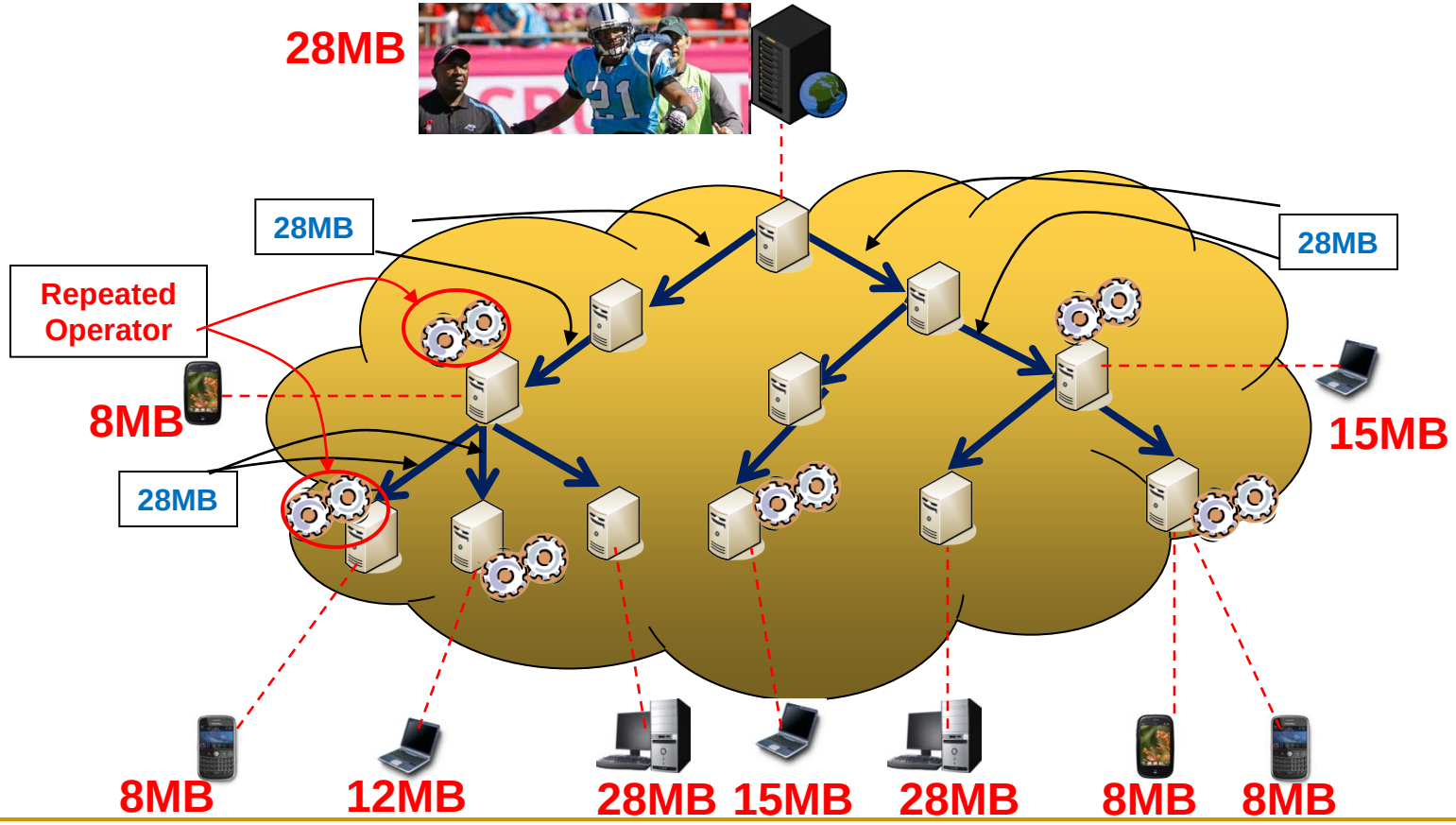
Challenges

- Option 1: Perform all the required customizations in the sender broker



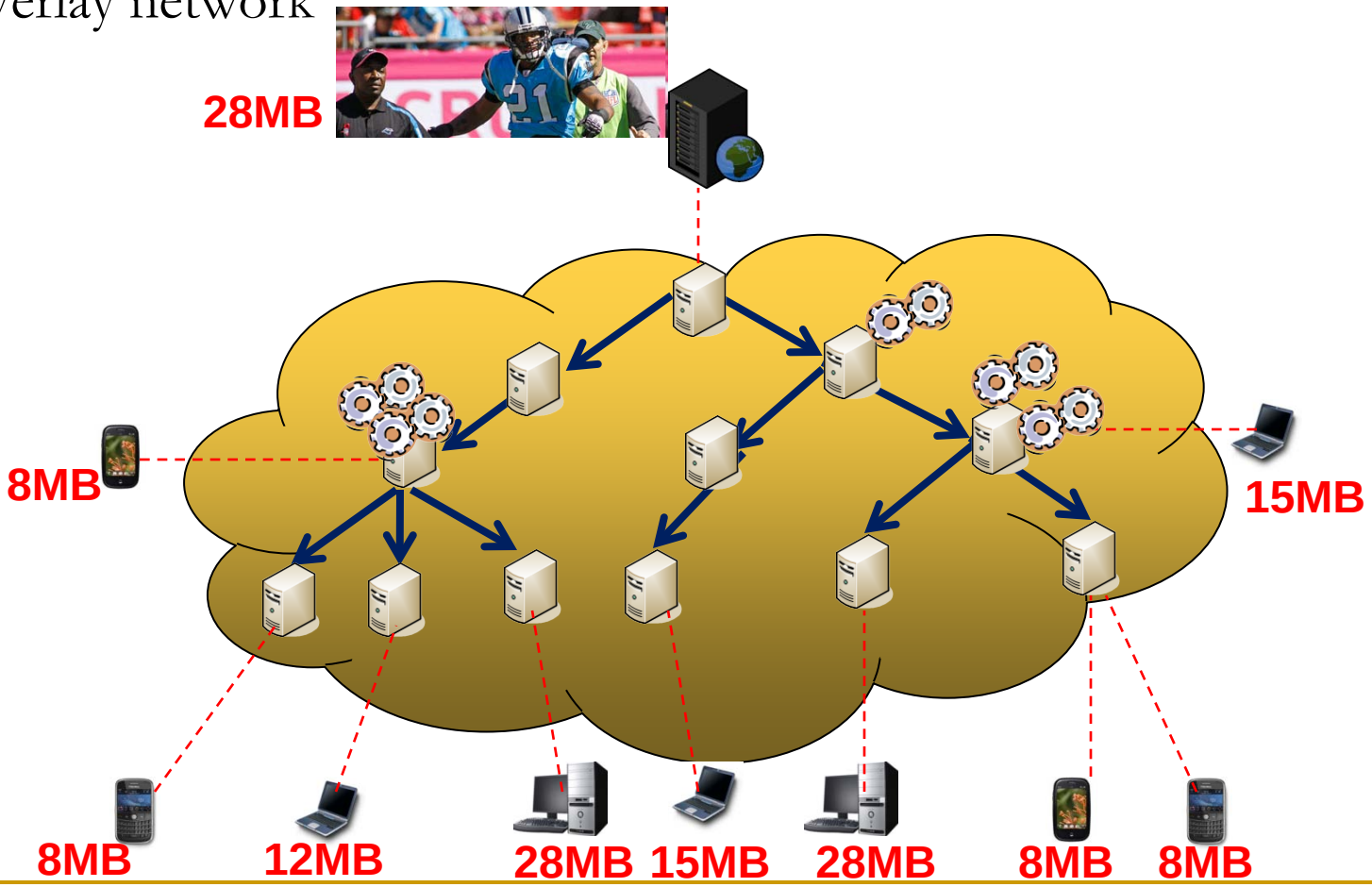
Challenges

- Option 2: Perform all the required customization in the proxy brokers (leaves)



Challenges

- Option 3: Perform all the required customization in the broker overlay network



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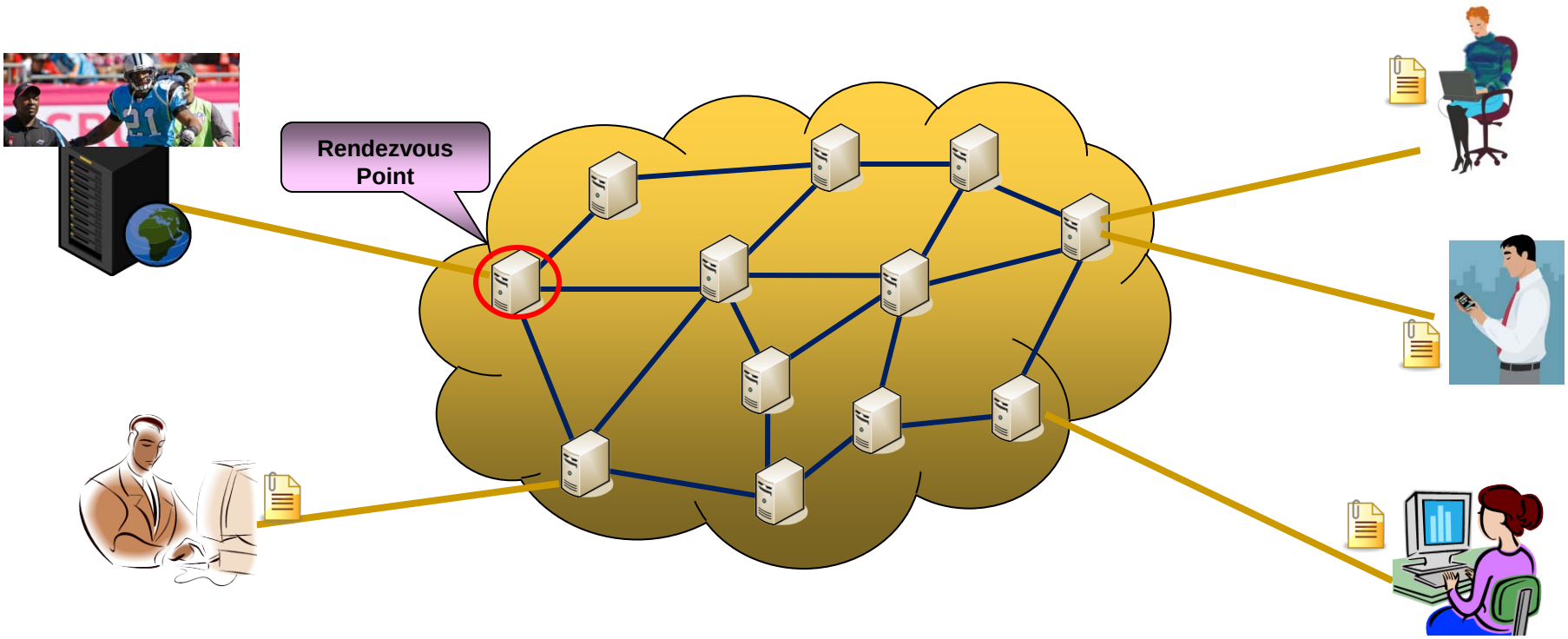
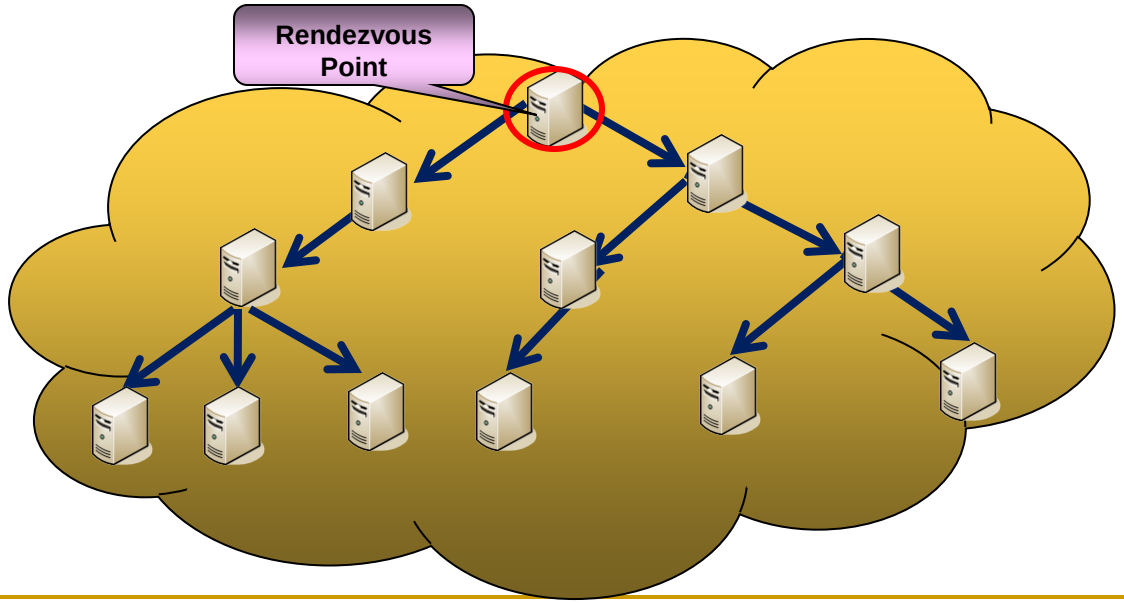
DHT-based pub/sub

- DHT-based routing schema,
  - We use Tapestry [ZHS04]



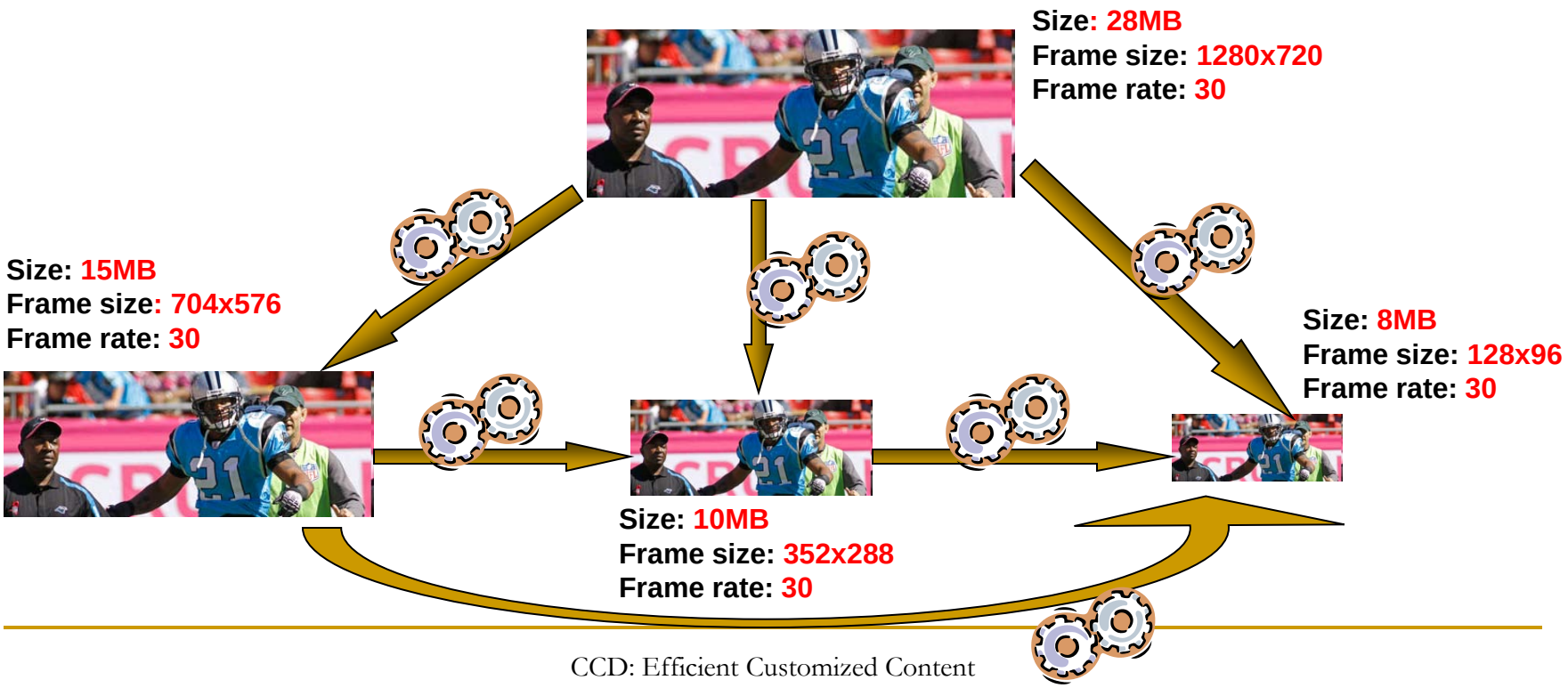
Dissemination tree

- For a published content we can estimate the dissemination tree in the broker overlay network
  - Using DHT-based routing properties
  - The dissemination tree is rooted at the corresponding rendezvous broker



Content Adaptation Graph (CAG)

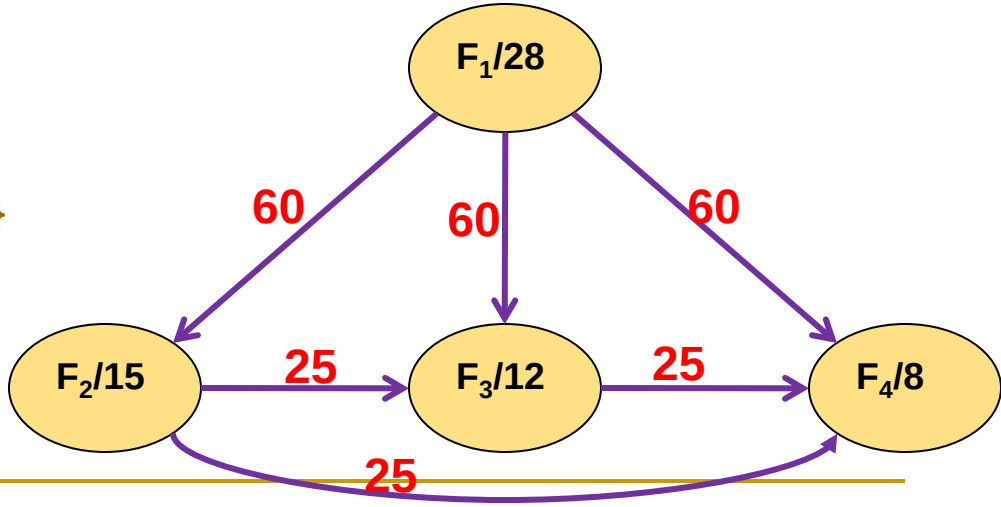
- All possible content formats in the system
- All available adaptation operators in the system



Content Adaptation Graph (CAG)

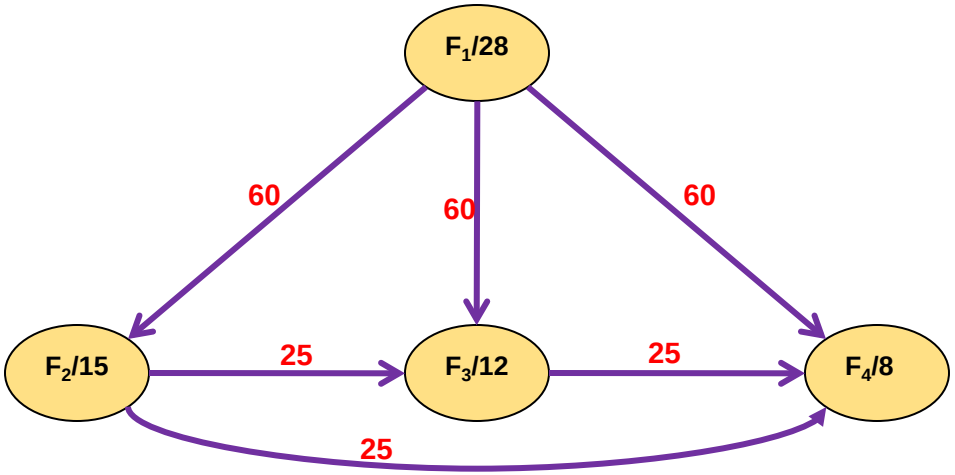
- A transmission (communication) cost is associated with each format
  - Sending content $\mathbb{C}$ in format F_i from a broker to another one has the transmission cost of $\mathcal{T}_{F_i}(\mathbb{C})$
- A computation cost is associated with each operator
  - Performing operator $O_{(i,j)}$ on content $\mathbb{C}$ has the computation cost of $\mathcal{C}_{O_{(i,j)}}(\mathbb{C})$

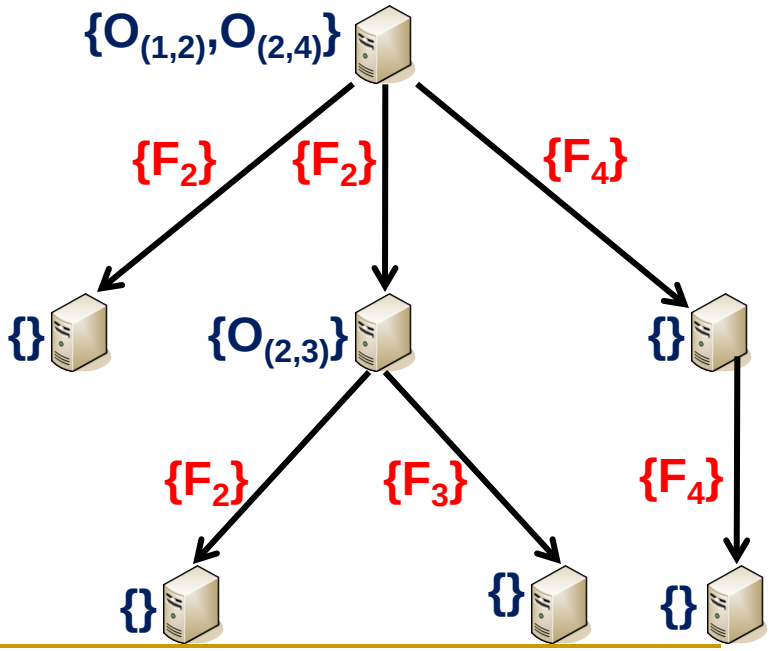
$V=\{F_1,F_2,F_3,F_4\}$
$E=\{O_{(1,2)},O_{(1,3)},O_{(1,4)},O_{(2,3)},O_{(2,4)},O_{(3,4)}\}$



CCD plan

- A CCD plan for a content is the dissemination tree:
  - Each node (broker) is annotated with the operator(s) that are performed on it
  - Each link is annotated with the format(s) that are transmitted over it





CCD plan cost

- Communication cost for a plan, $\tau_{\mathbb{P}}$
  - Sum of all costs for the formats transmitted through all edges
- Computation cost for a plan, $\varphi_{\mathbb{P}}$
  - Sum of the costs for all operators in all plan nodes
- Total CCD plan cost

$$\Theta_{\mathbb{P}}(\mathbb{C}) = \alpha\tau_{\mathbb{P}} + \beta\varphi_{\mathbb{P}}$$

  - $\varphi_{\mathbb{P}}$ and $\tau_{\mathbb{P}}$ are normalized values, $\alpha, \beta \geq 0$

Problem definition

- **For a given CAG and dissemination tree, $\mathbb{T}$, find CCD plan $\mathbb{P}$ with minimum total cost.**

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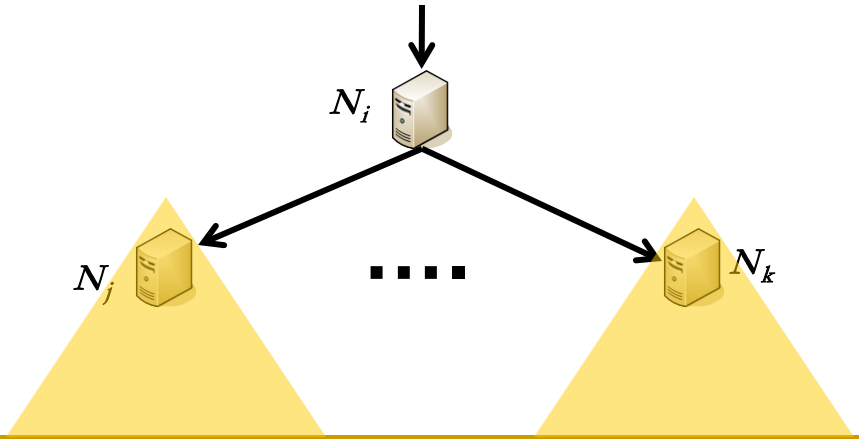
CCD algorithm

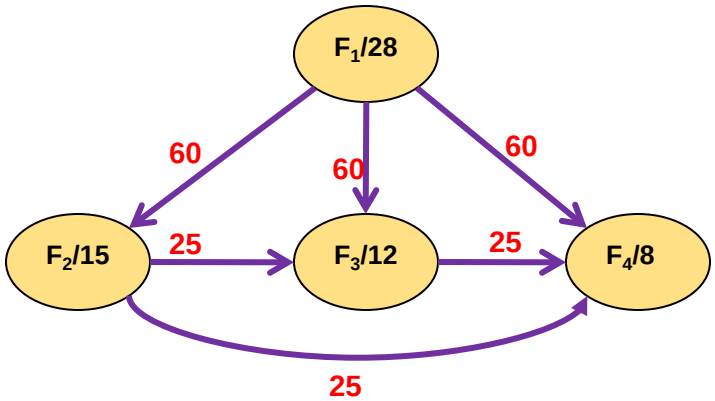
- Input:
  - A dissemination tree
  - A CAG
  - The initial format
  - Requested formats by each broker
- Output:
  - The minimum cost CCD plan

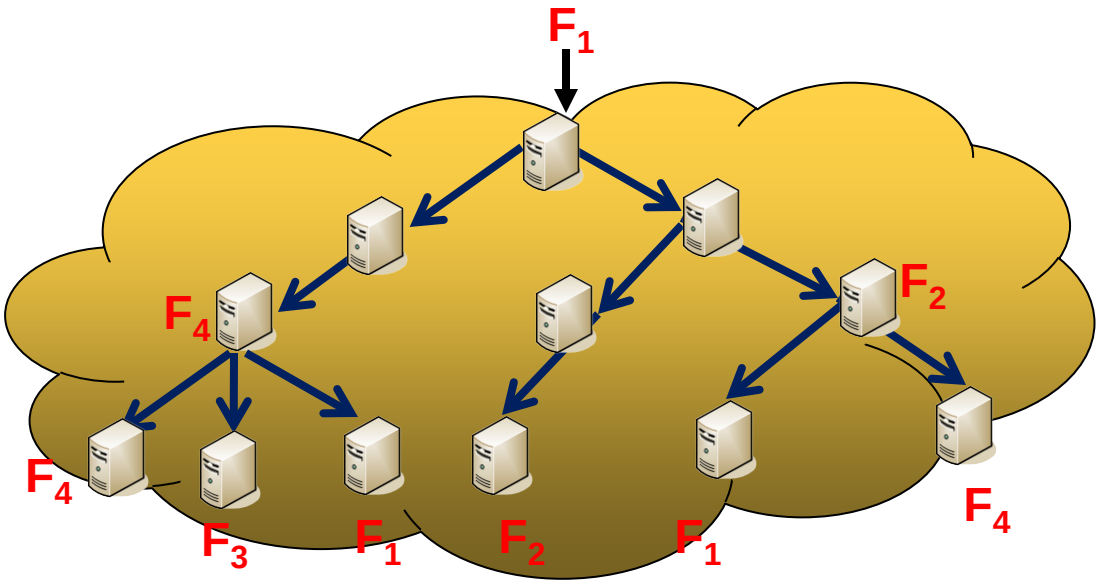
CCD algorithm

- Based on dynamic programming
- Annotates the dissemination tree in a bottom-up fashion
- For each broker:
  - Assume all the optimal sub plans are available for each child
  - Find the optimal plan for the broker accordingly



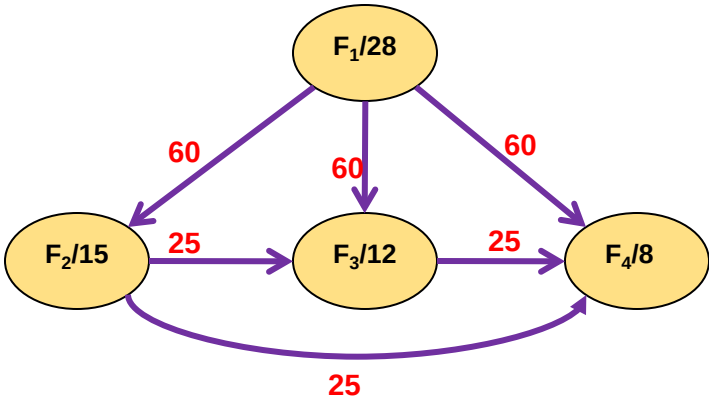
CCD algorithm

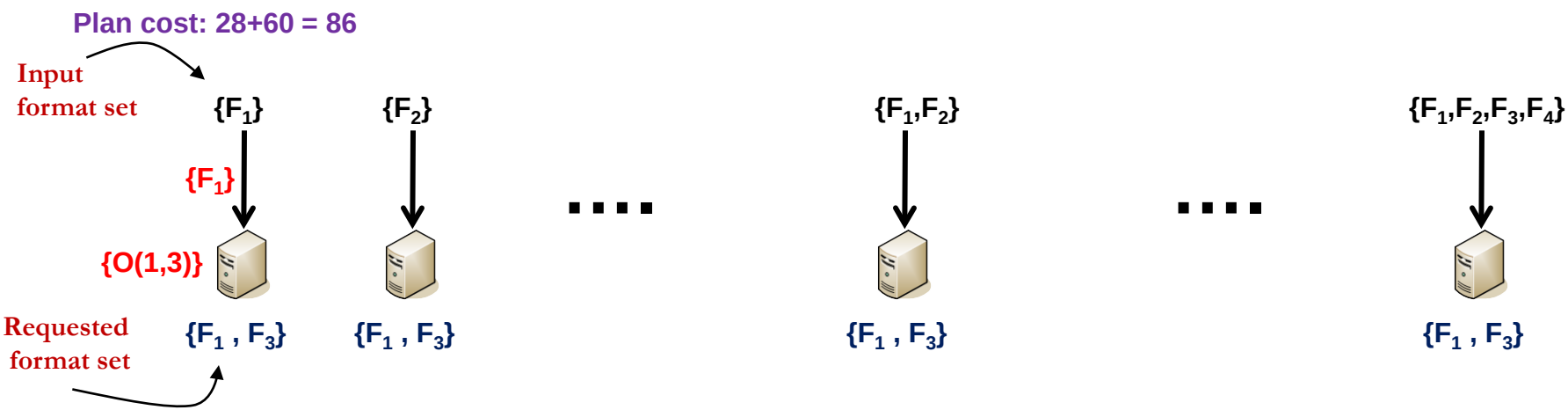




CCD algorithm in leaf broker

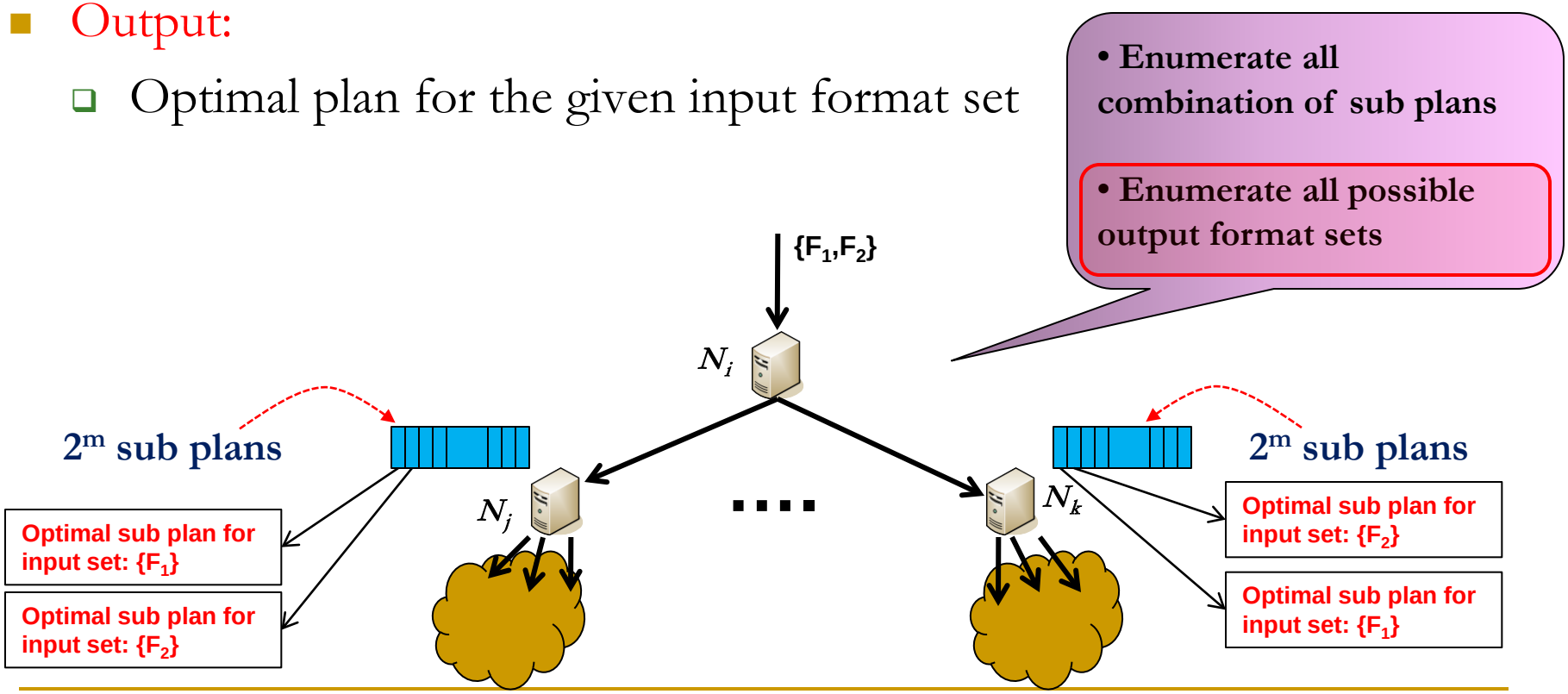
- Input:
  - All possible input format sets
  - Requested formats
- Output:
  - Optimal plan for each input format set





CCD algorithm in for a non-leaf broker

- Input:
  - All possible input format sets
  - Optimal sub plan for child nodes for any given input format set
- Output:
  - Optimal plan for the given input format set



Complexity of CCD algorithm

- Algorithm complexity $O(nk_{avg}2^{3m}\mathbb{S})$
  - n : number of nodes in the tree
  - k_{avg} : average number of children for a node
  - m : number of formats in the CAG
  - $\mathbb{S}$: complexity of minimum conversion cost computation in CAG
- Exponential in m, CAG size

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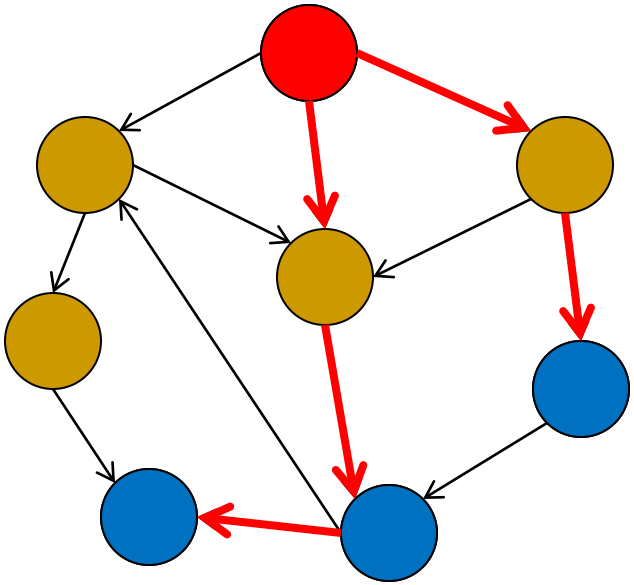
CCD Problem is NP-hard

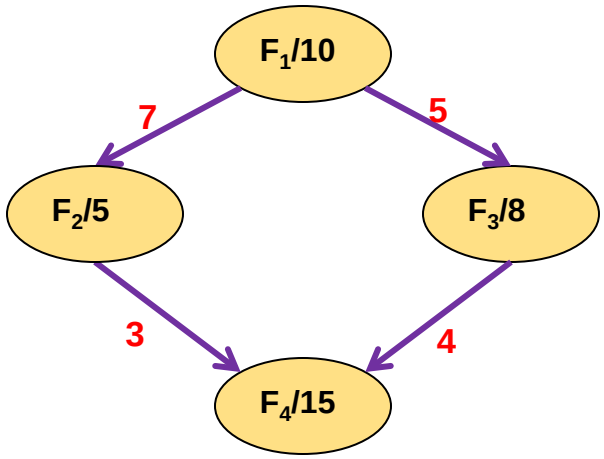
- Directed Steiner tree problem can be reduced to CCD

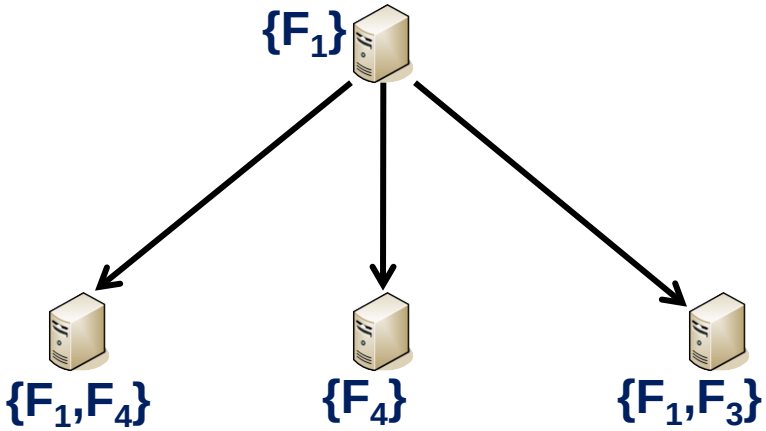
Given a directed weighted graph G(V,E,w) , a specified root r and a subset of its vertices S, find a tree rooted at r of minimal weight which includes all vertices in S.

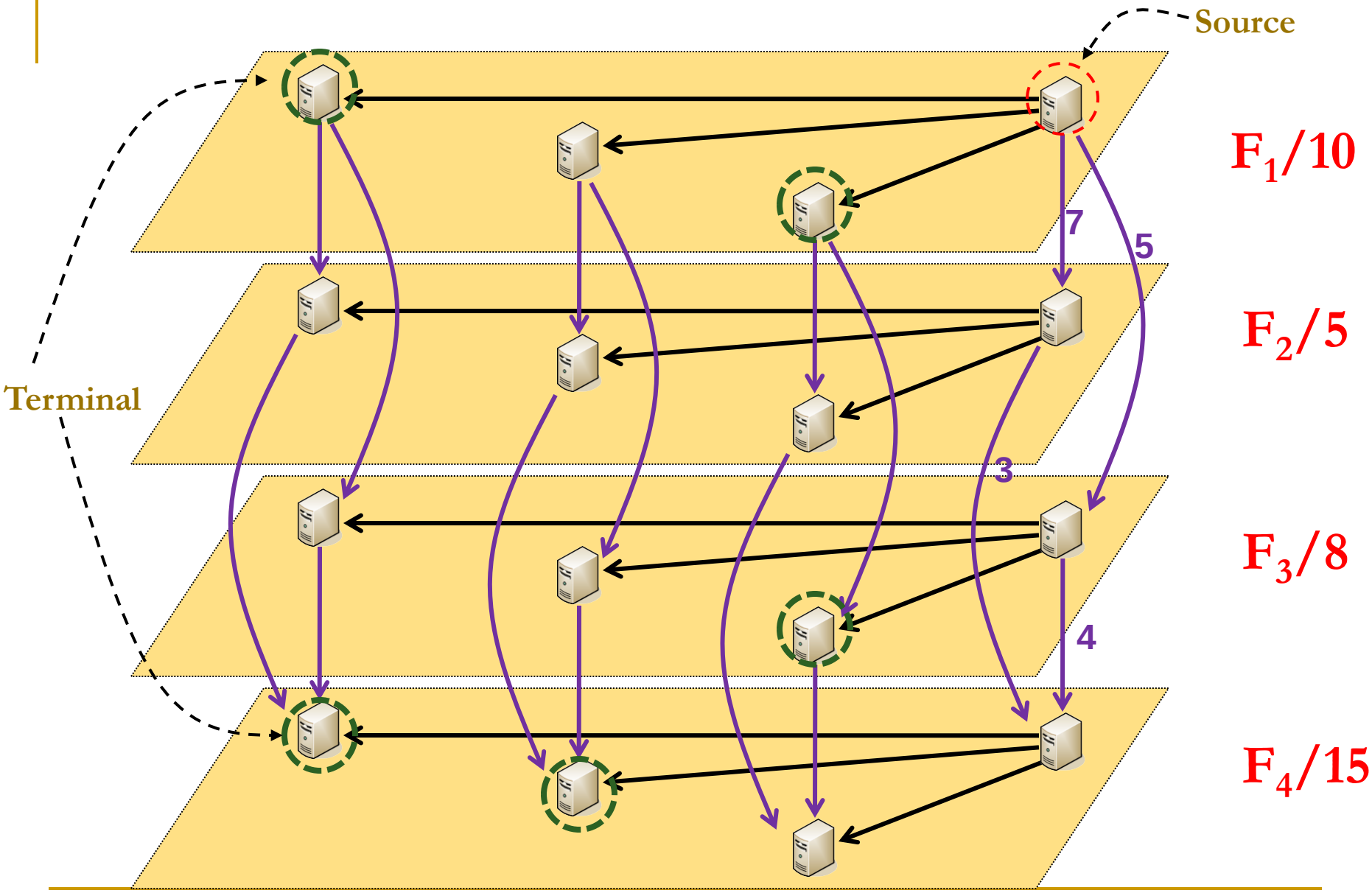


Multilayer graph representation

- Cartesian product of CAG and dissemination tree





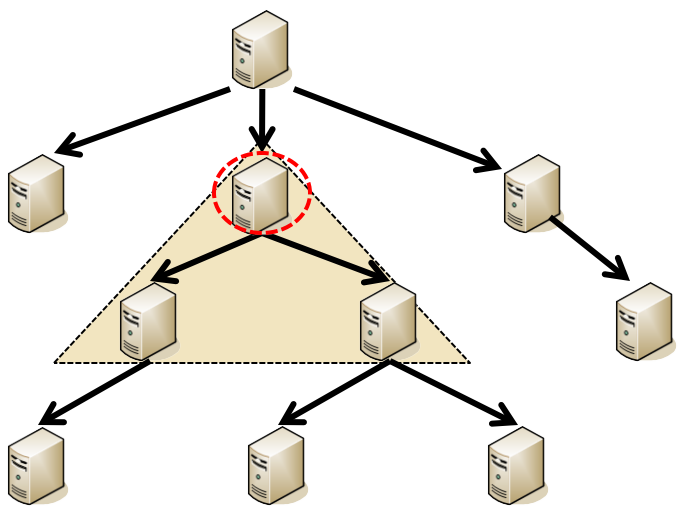

Source
Terminal
$F_1/10$
$F_2/5$
$F_3/8$
$F_4/15$
7
5
3
4

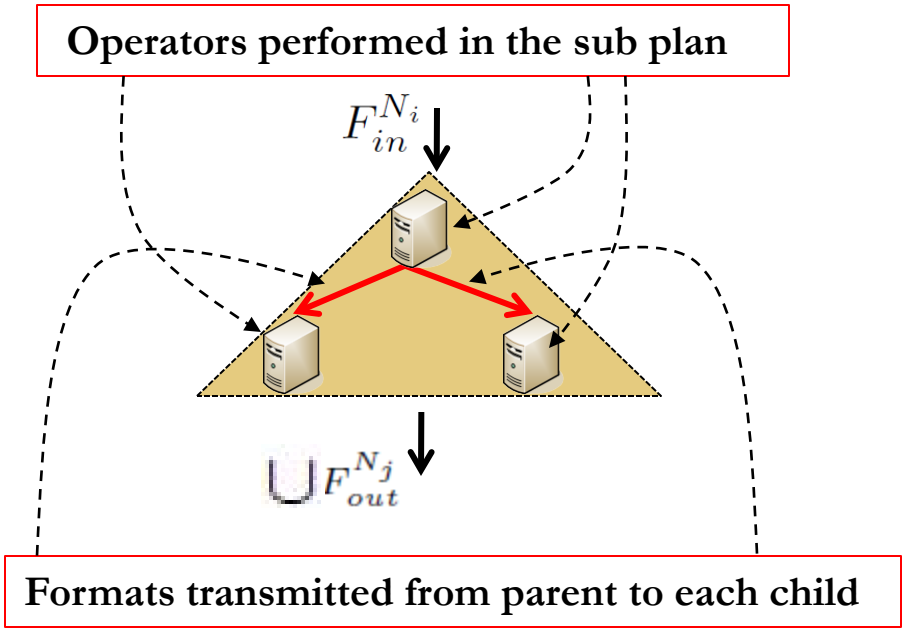
Approximate Steiner tree over multilayer graph

- A $(i(i-1)k^{\frac{1}{i}})$-approximate has been proposed
- k is the number of terminals
- i is the algorithm approximation parameter
- Time complexity is $O(v^{i} \; k^{2i})$
- v is the number of nodes in the multilayer graph
- High time complexity for large dissemination trees
  - $v = n \, . \, m$
- Example:
  - Number of brokers (n)= 1000, Number of formats (m) = 20
  - $v = 20000$, $k <= 20000$

Heuristic CCD algorithm

- An iterative heuristic algorithm
  - Start with an initial plan
  - Pick a node in the plan for refinement
  - Refine the one level sub plan rooted at the selected node using multilayer graph



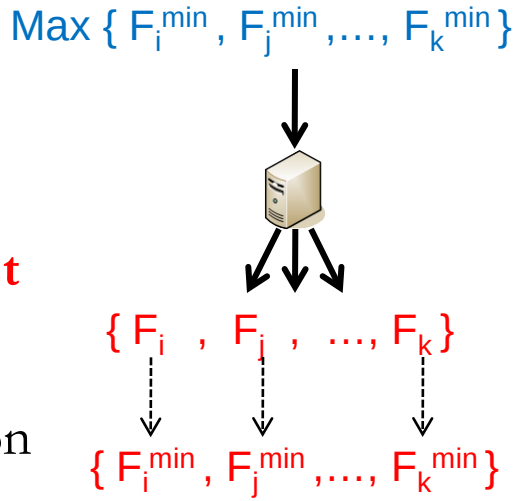


Heuristic CCD algorithm

- Initial plan selection
  - Any valid plan can be used as initial plan
    - All in leaves
    - All in root
    - Single-format
- Node selection for plan refinement
  - Random
  - Slack
    - Maximum expected benefit (cost reduction) from selecting a node

Slack computation for a node

- Communication cost slack
  - Current communication cost – lower bound for communication cost
  - **Estimation of lower bound for communication cost**
- Computation cost slack
  - Current computation cost-lower bound for computation cost
  - **Estimation of lower bound for computation cost**
- Total slack for a node
  - **Communication slack + Computation slack**



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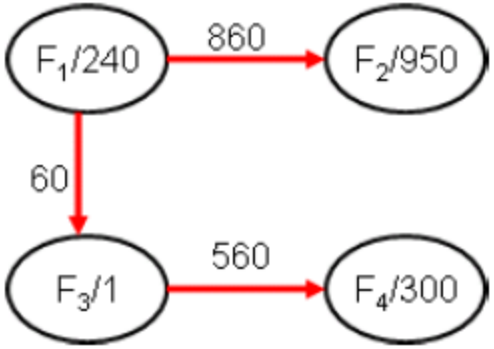
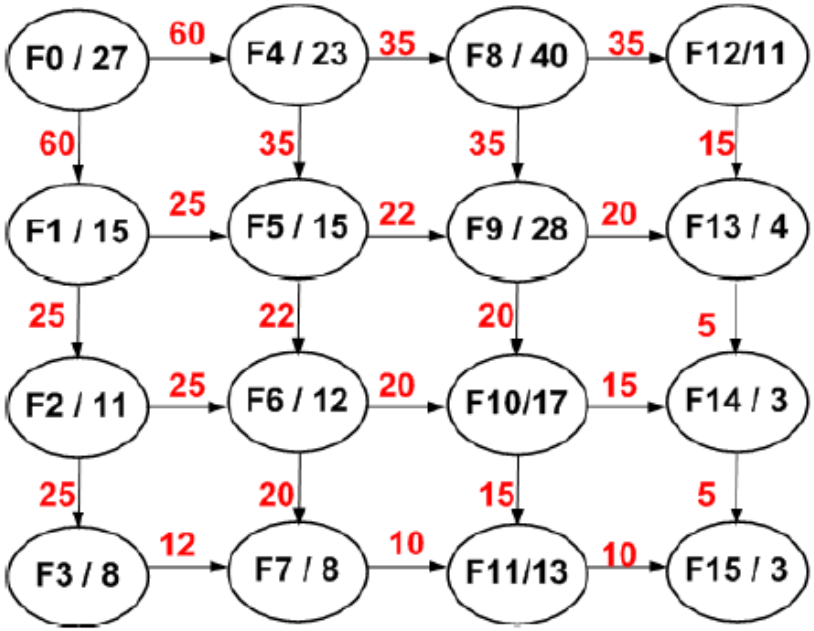
Experimental evaluation

- System setup
  - 1024 brokers
  - Matching ratio: percentage of brokers with matching subscription for a published content
    - Zipf and uniform distributions
  - Communication and computation costs are assigned based on profiling

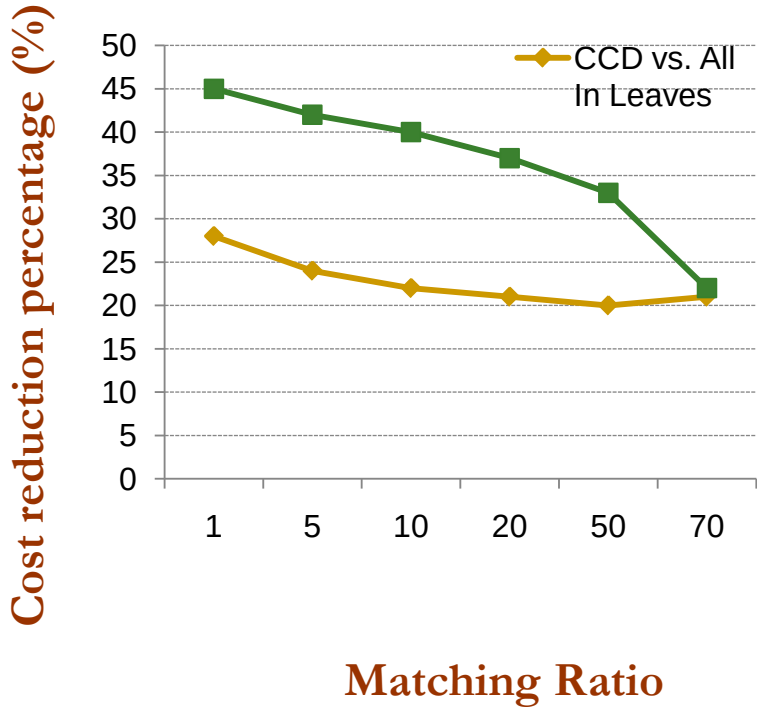
Experimental evaluation

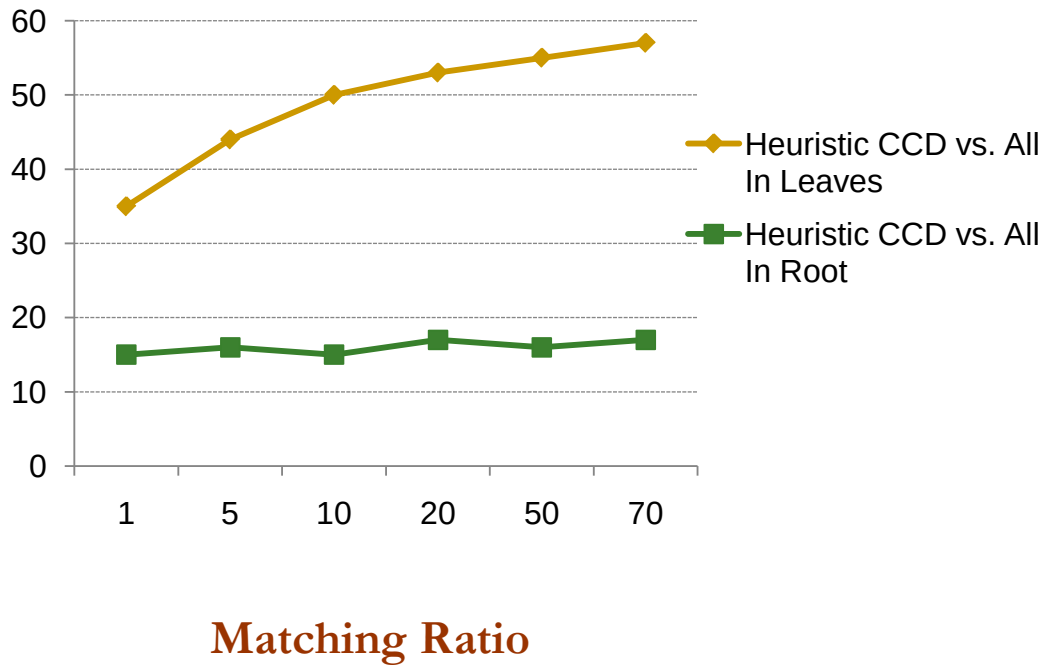
- Dissemination scenarios
  - Annotated map
  - Customized video dissemination
  - Synthetic scenarios



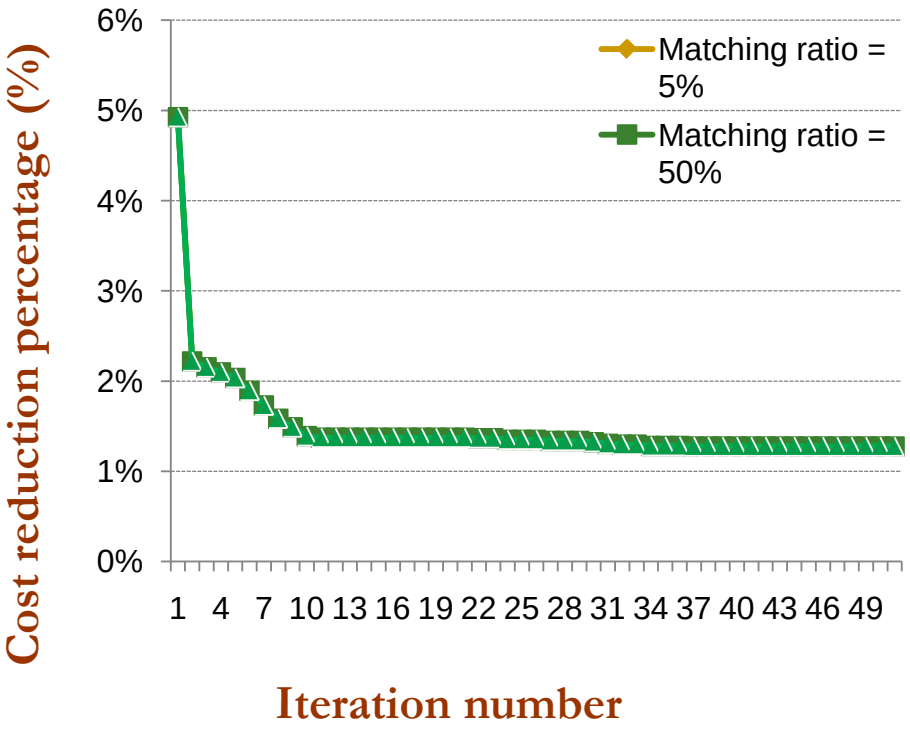


Cost reduction in CCD and Heuristic CCD algorithms

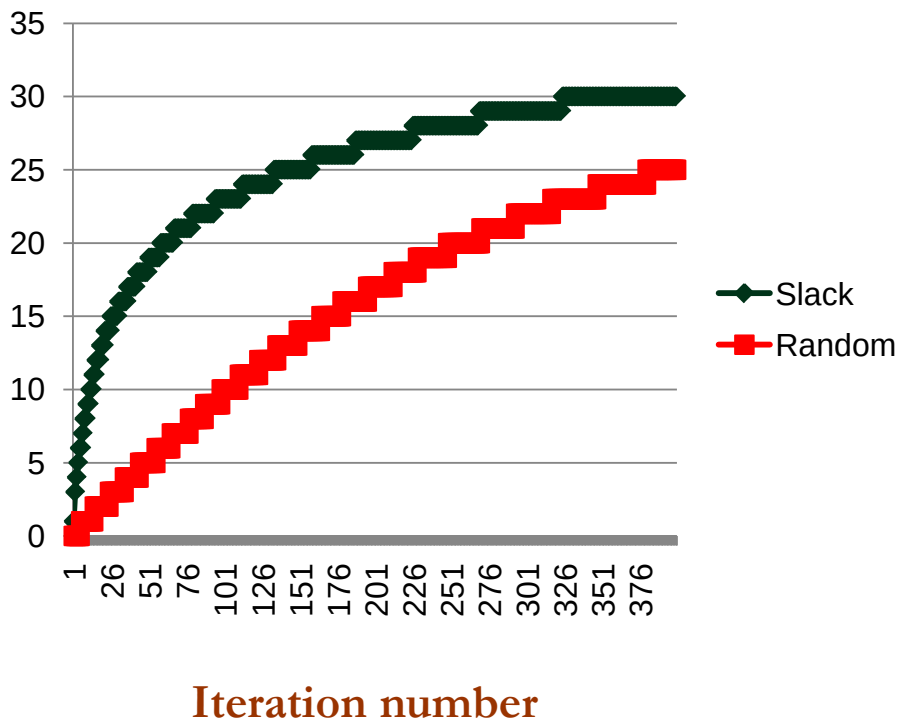




CCD vs. heuristic CCD



Slack vs. Random next step selection



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Heterogeneity

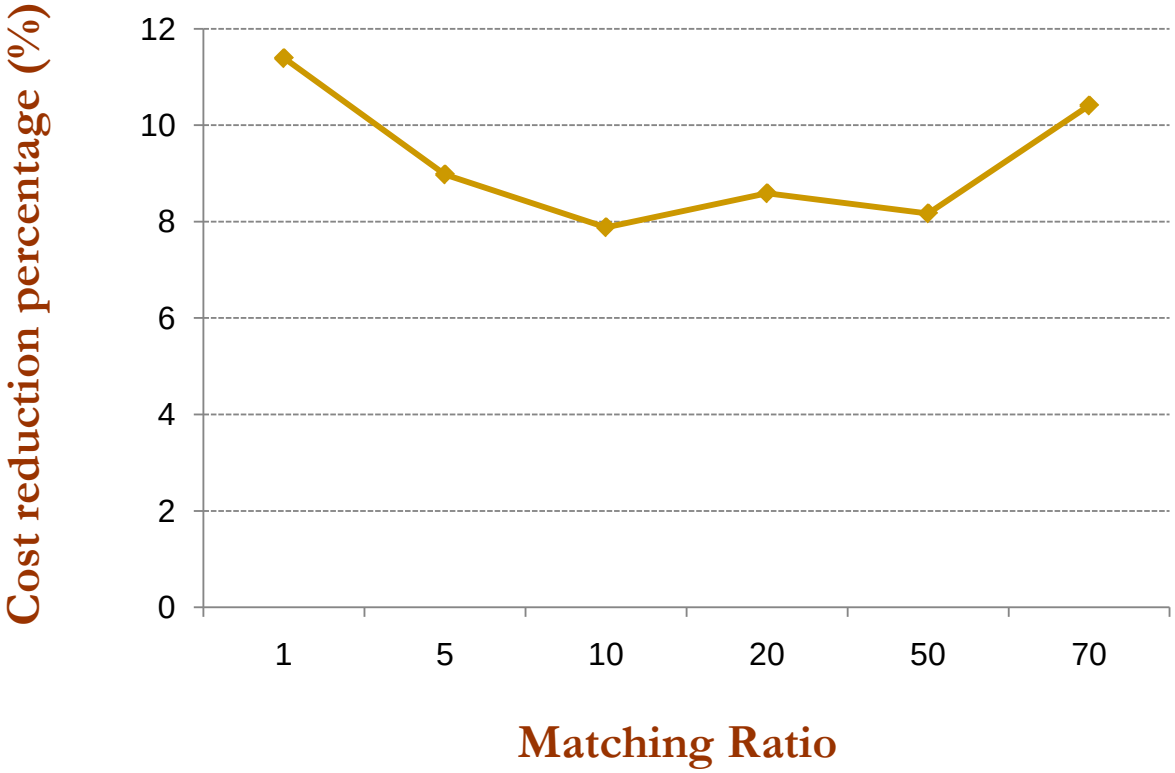
- Cost factor for performing operators at a broker
  - C_{N_i} : Cost factor for broker *Ni*
  - Cost of performing operator $O_{(i,j)}$ at N_i is computed as follow

$$\mathcal{C}_{O_{(i,j)}}(\mathbb{C}) \times C_{N_i}$$

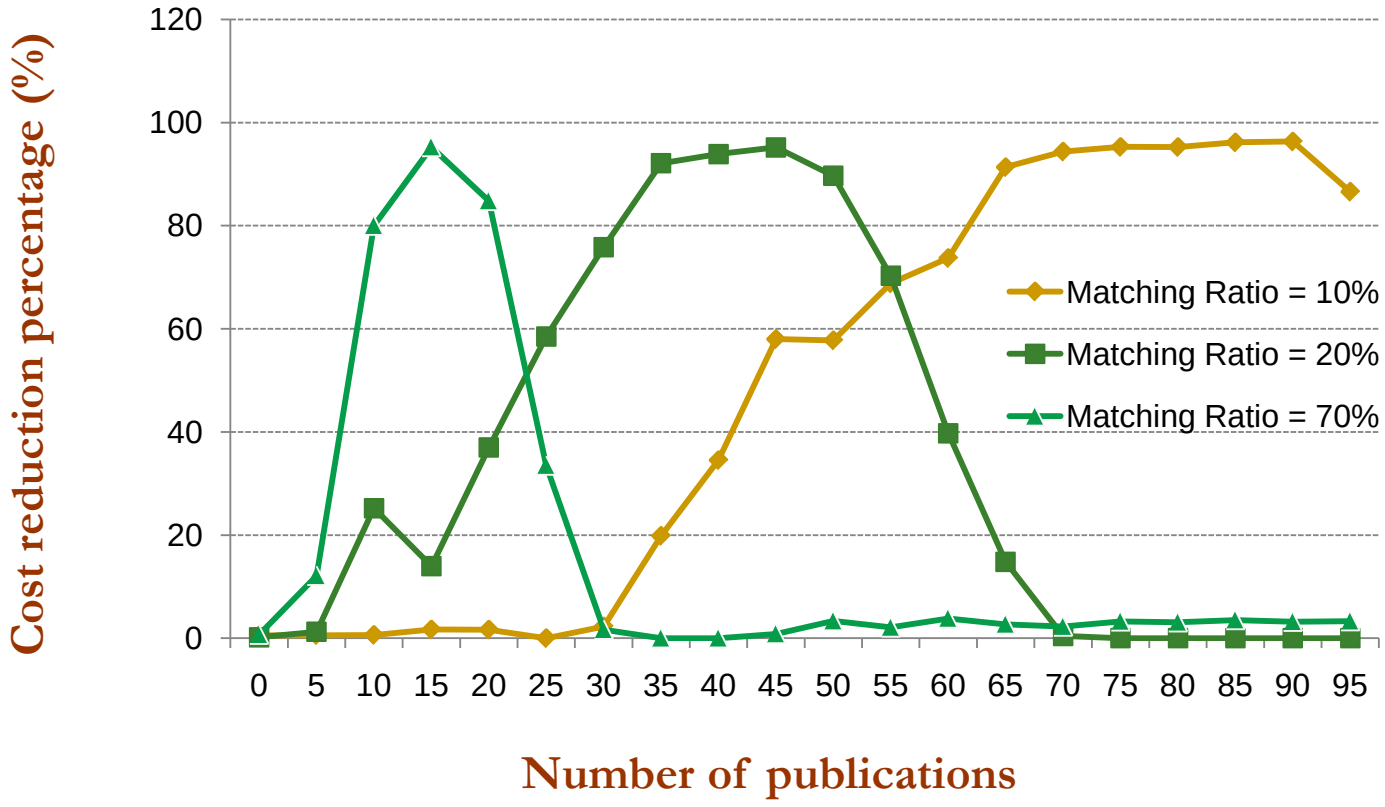
- Every link in the tree also has a cost factor
  - $C_{<N_i,N_j>}$: Cost factor for link $<N_i,N_j>$
  - Cost of transmitting content in format F_i over the link is computed as follow

$$\mathcal{T}_{F_i}(\mathbb{C}) \times C_{<N_i,N_j>}$$

CCD plan cost reduction considering heterogeneity



Concurrent publications



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