CpE654 / NIS654
Design and Analysis of Network Systems

Flow Analysis

Introduction

- The network analysis process yields:
  - ✓ The requirement specifications
  - ✓ The requirement maps
- From this analysis, we derive flow specifications
- Why Flow Analysis?
  - for end-to-end network capacities as the first step for the desired performance of the network.

What are Flows
(also known as traffic flows or data flows)

- Flows are network traffic with common attributes by:
  - Application,
  - Source/destination addresses,
  - Directionality,
  - Type of information carried,
  - Port numbers, or
  - Other end-to-end information.

- Performance requirements per attribute, e.g., application, service metrics, etc.) are part of flow descriptions.

- Flow analysis is the process of characterizing traffic flows for a network (where they occur and what levels of performance they require).

What are Flows (Contd.)

- Flows provide a network perspective on traffic, associated with users, devices, and applications carried over the network.
- Flows give perspective of traffic from end-to-end for applications, devices, networks, and end users.
- Flows can be examined on a link-by-link or network-by-network basis.

Objectives of Flow Analysis

- To shows how and where requirements combine and interact
- Provide information on needed diversity and hierarchy in the network
- To choose interconnection strategies, such as switching or routing.
- Flow analysis is not to show every possible flow in a network
- But to show those flows with greatest impact on the network architecture and design.
- It help develop capacity for desired performance

Flow Representation

Flow 1 (Bidirectional)
100 Kb/s Upstream

500 Kb/s Downstream

Flow 2 (unidirectional)
100Kb/s, 40ms

Upstream

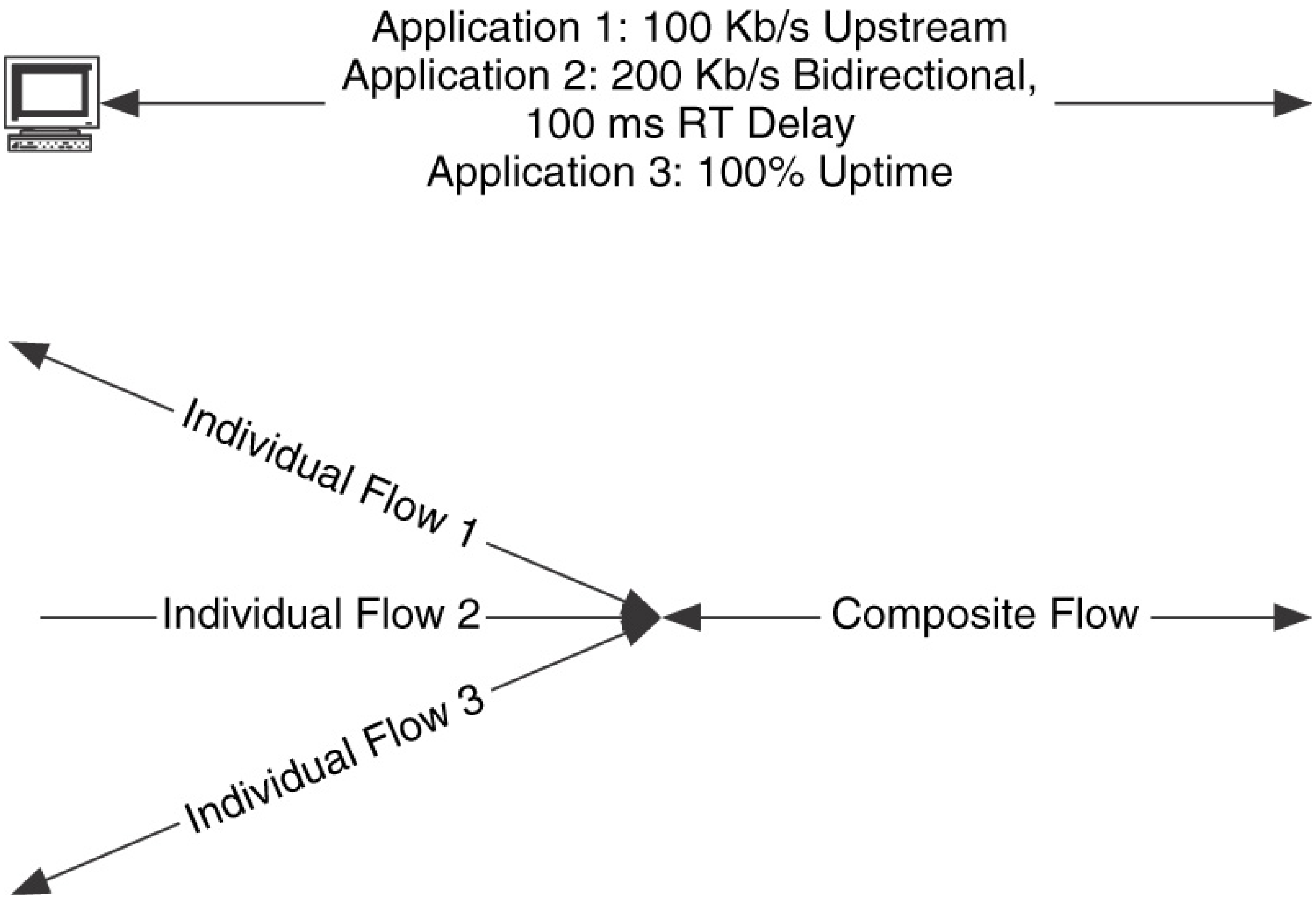
Flow representation shows:

- Unidirectional or bidirectional arrows
- Bandwidth and performance requirements

Two Types of Flows

- ***<u>An individual flow:</u>*** is the flow for a single session of an application. Individual flows are derived directly from the requirements specification or are estimated from our best knowledge about the application, users, and devices, as well as their locations.
- ***<u>A composite flow:</u>*** is a combination of requirements from multiple applications or of individual flows that share a common link, path, or network.

Composite Flow Example



Examples of Flows

Individual- One way with delay requirements

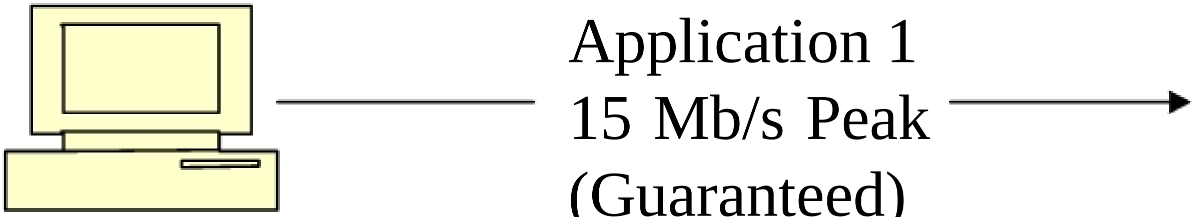
Individual –Two way flow with capacities in each direction

Composite- Three separate flows with performance specified for each

Individual – with flow profile specified

Flows with Guaranteed Requirements

- Flows with guaranteed requirements are left as individual flows
- Not consolidated with other flows into a composite flow.

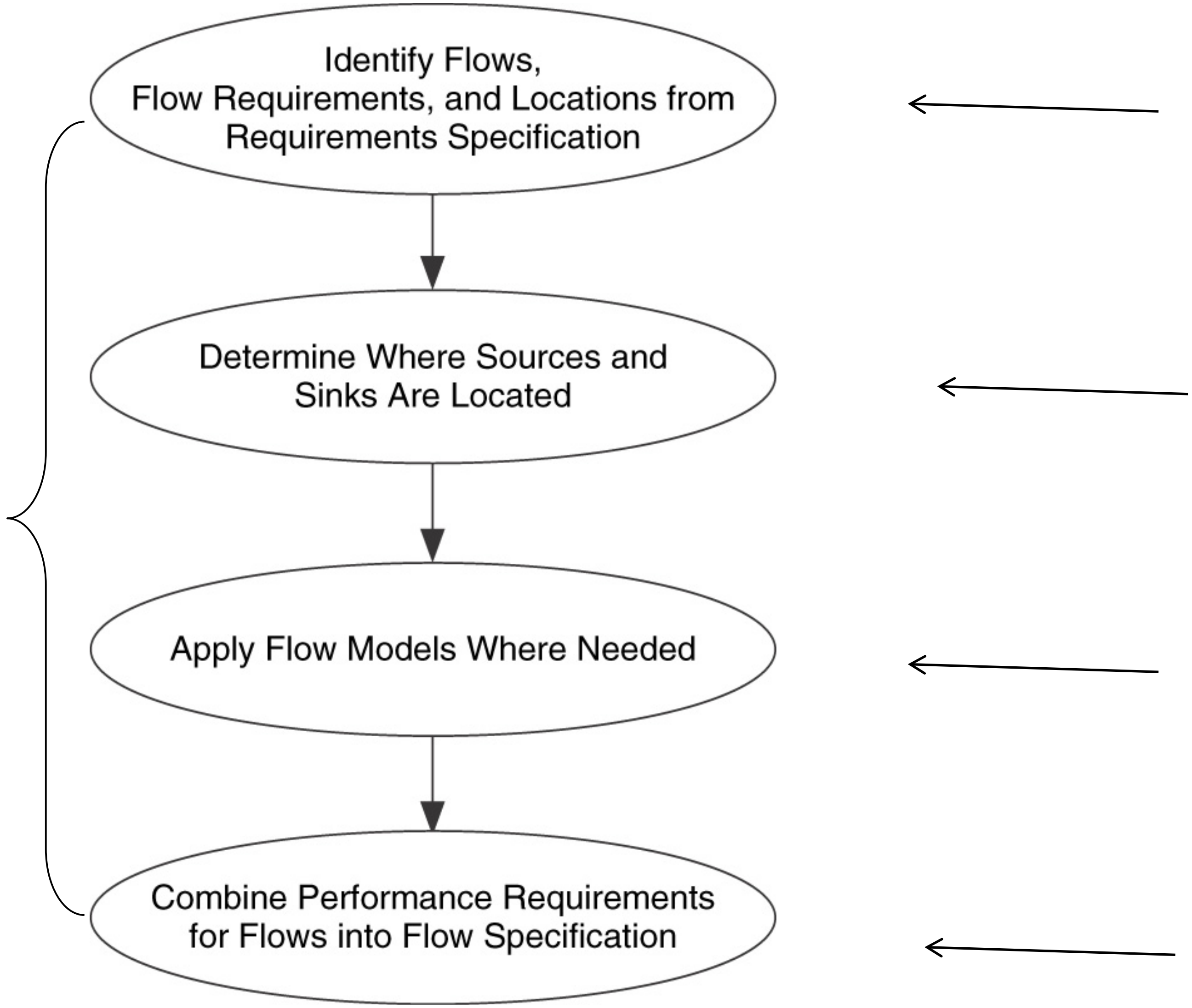


Critical Flows

- Those flows which are more important than others
  - Demanding higher performance
  - stricter requirements (delays, packet loss)
- Examples:
  - Flows generated by mission-critical, rate-critical, and real-time applications.
  - Flows serving more important users or applications.
- Critical flows often considered first in the network architecture and design.
- Critical flows with high, predictable, and/or guaranteed performance may drive the architecture and design from a service (capacity, delay, and RMA) perspective.

Process for Identifying and Developing Flows

We describe a step by step process for identifying and developing flows



Developing Flows

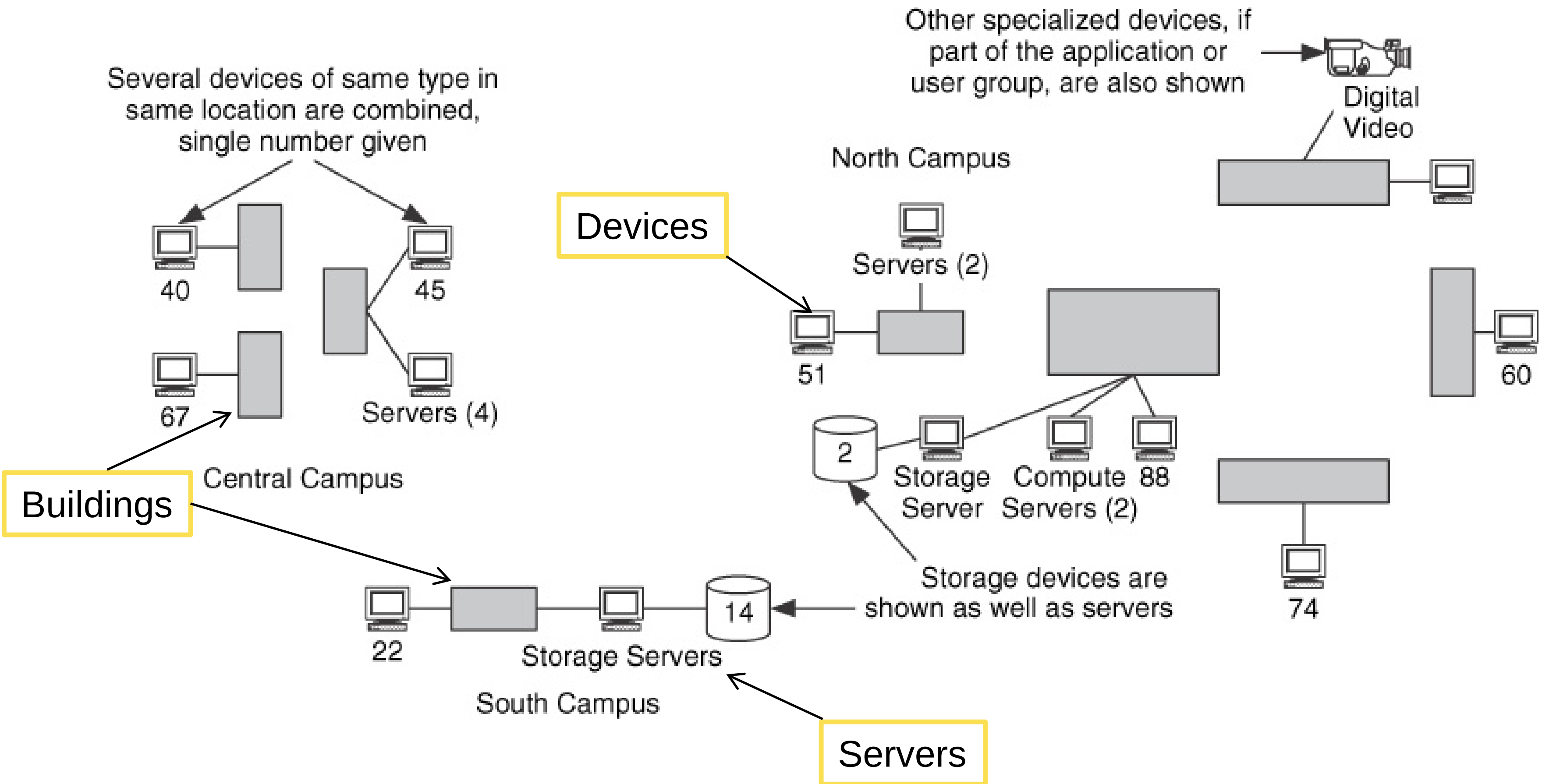
- Approach 1 - Focus one at a time on an application, an application group, a device, or a service (e.g., VoIP, video conferencing, storage).
    - Generally easier to handle
    - Requirements generally on individual application.
- Approach 2 – Developing a composite profile
- Approach 3 - Choose top N applications

Example of Approach 1
Focus on Individual Applications

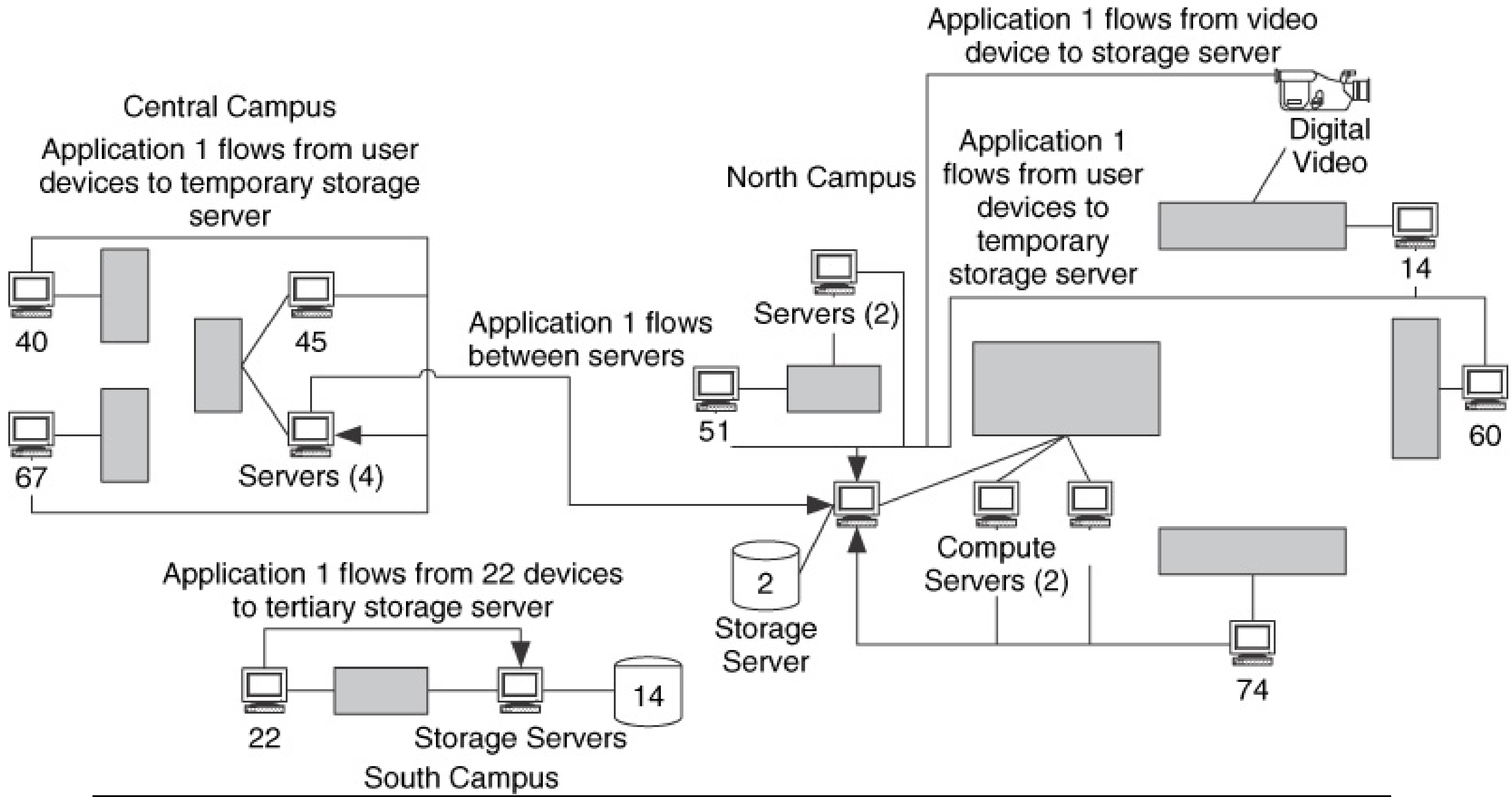
From requirements analysis, single session specific data is gathered by applications:

- Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%
- Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%
- Application 2 – Migrating to a remote server: Capacity 10Mb/s; Delay N/A; Reliability 100%

Example Approach 1: Data Migration Map of Device Locations



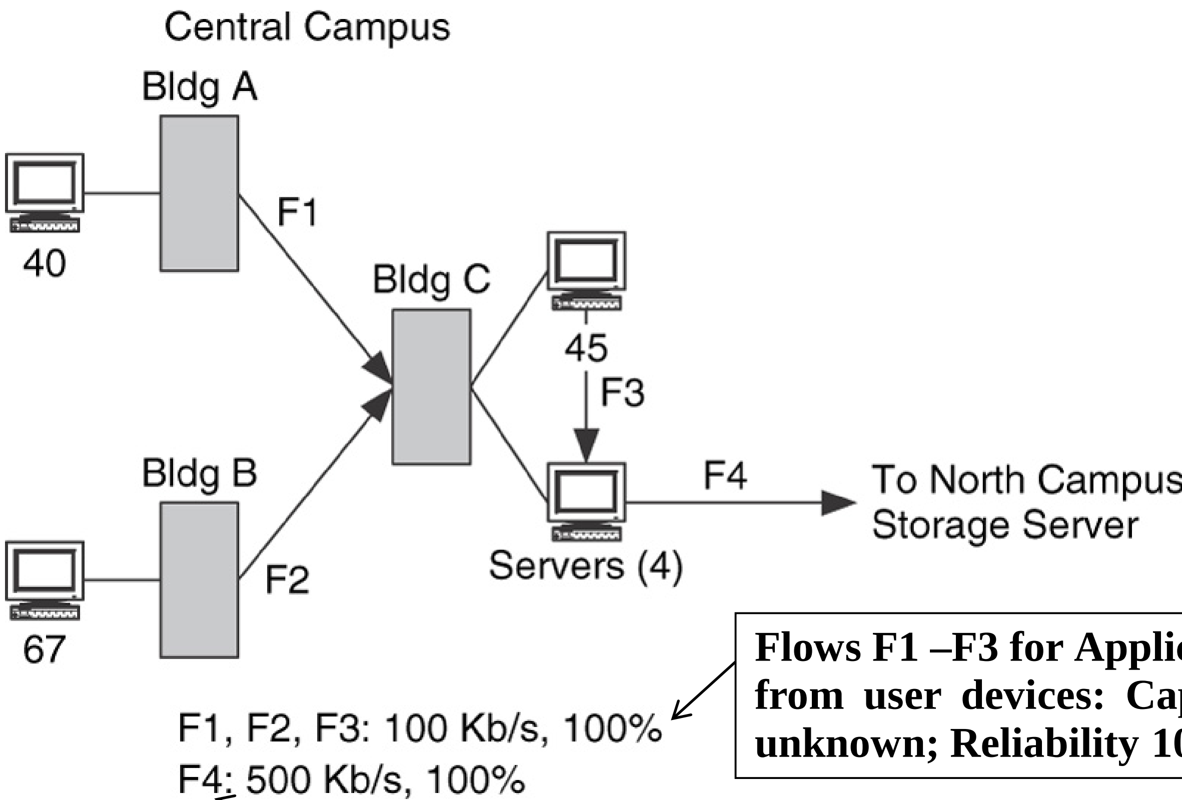
Example Data Migration – Approach 1 Flows for Application 1



Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%

Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%

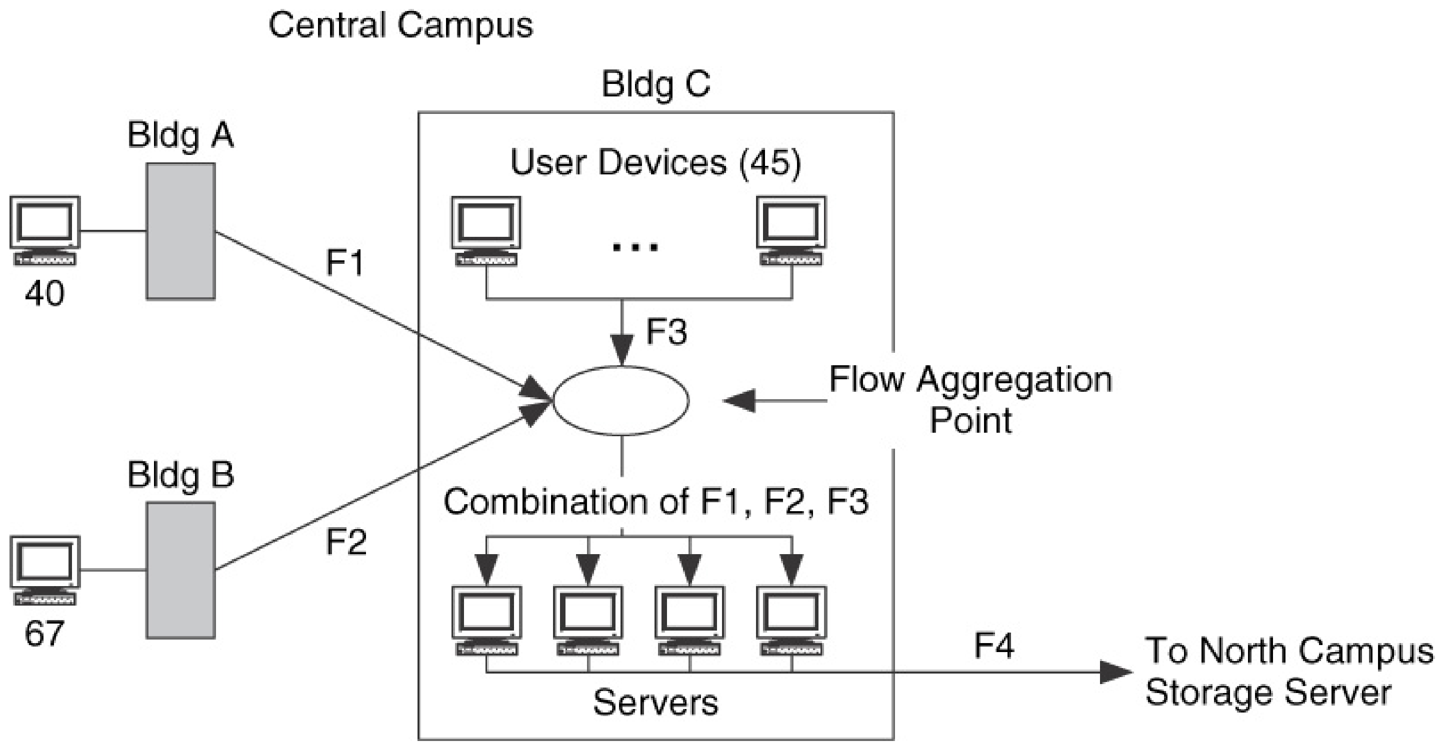
Example Data Migration Approach 1: Application 1 with Performance Information Added



Flows F1 –F3 for Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%

Flow F4 on Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%

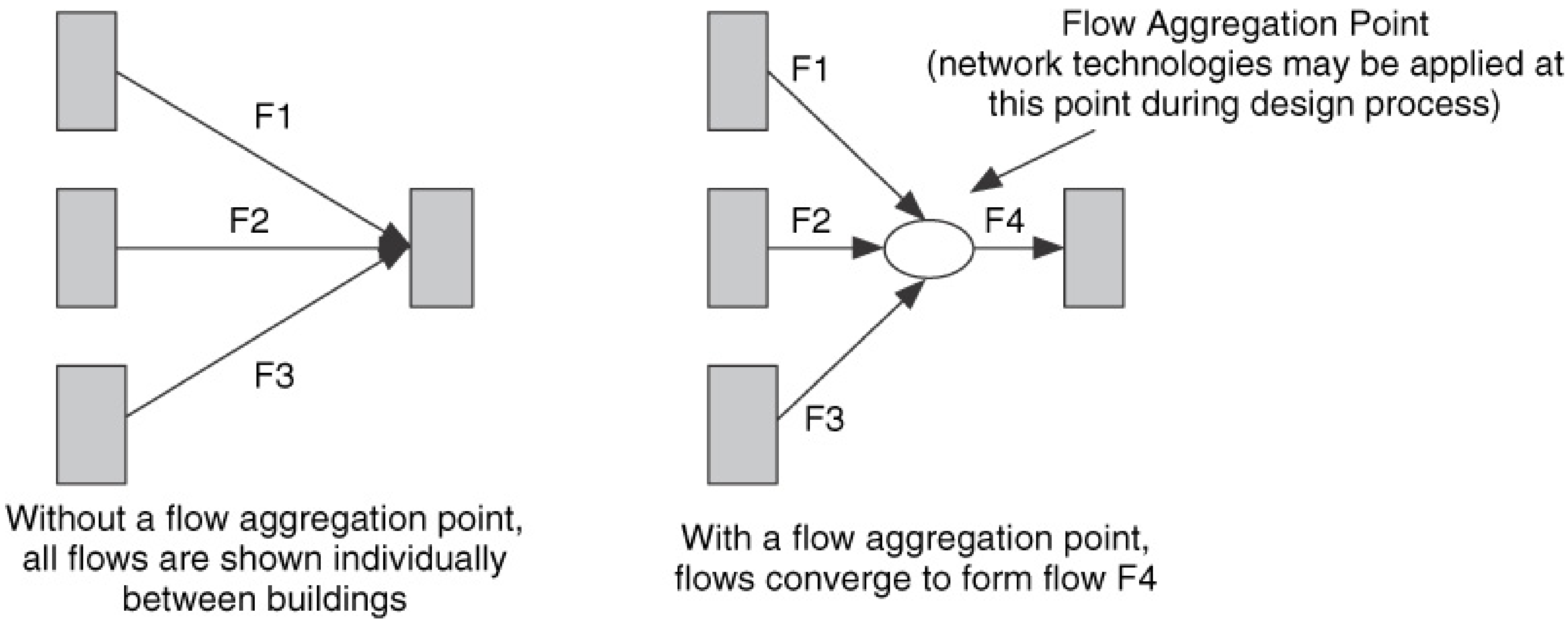
Example Data Migration Approach 1
Central Campus Flow for Application 1
With Aggregation point



F1, F2, F3 Flows for Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%

F4 Flow for Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%

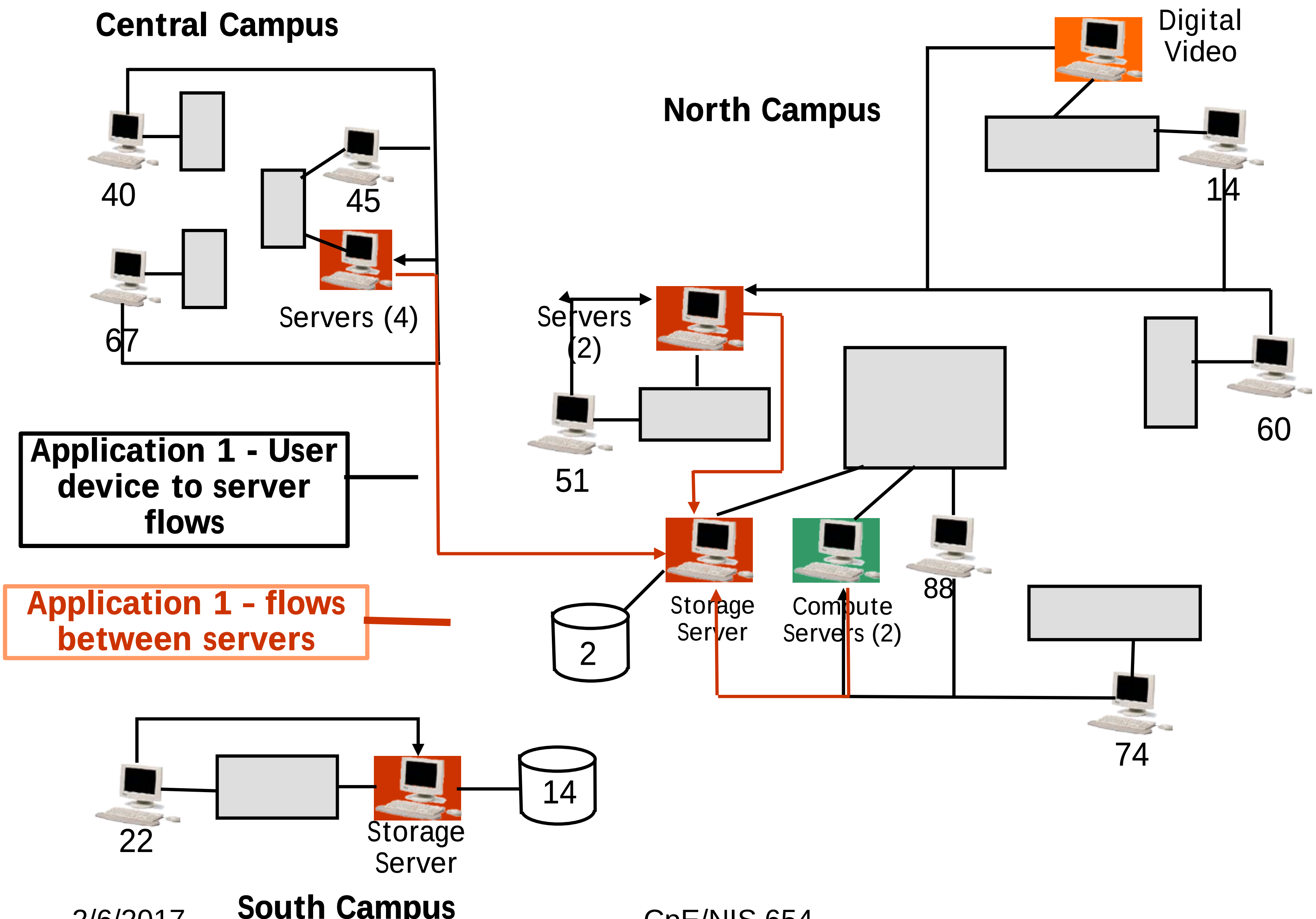
Example Data Migration Approach 1
Consolidating Flows



F1, F2, F3 Flows for Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%

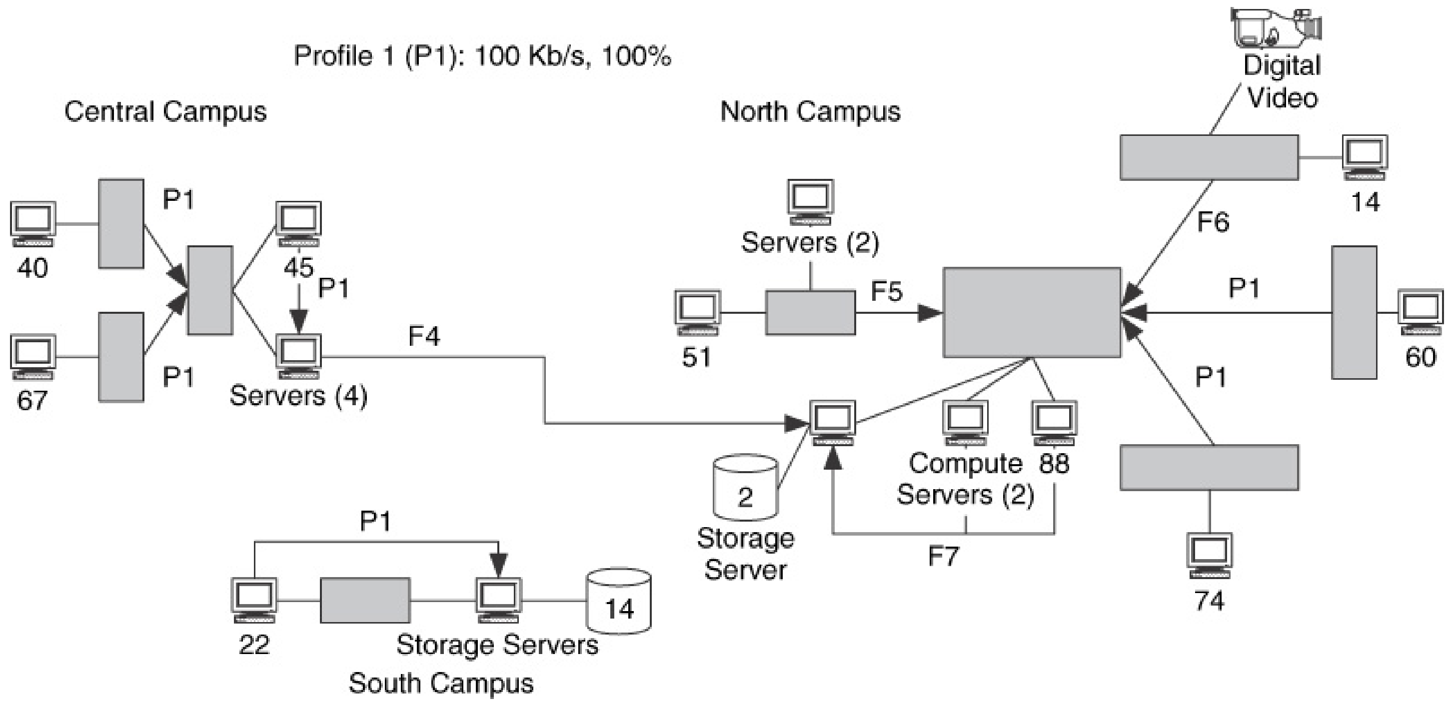
F4 Flow for Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%

Flows between devices for Application 1



Approach 2: Developing a Profile

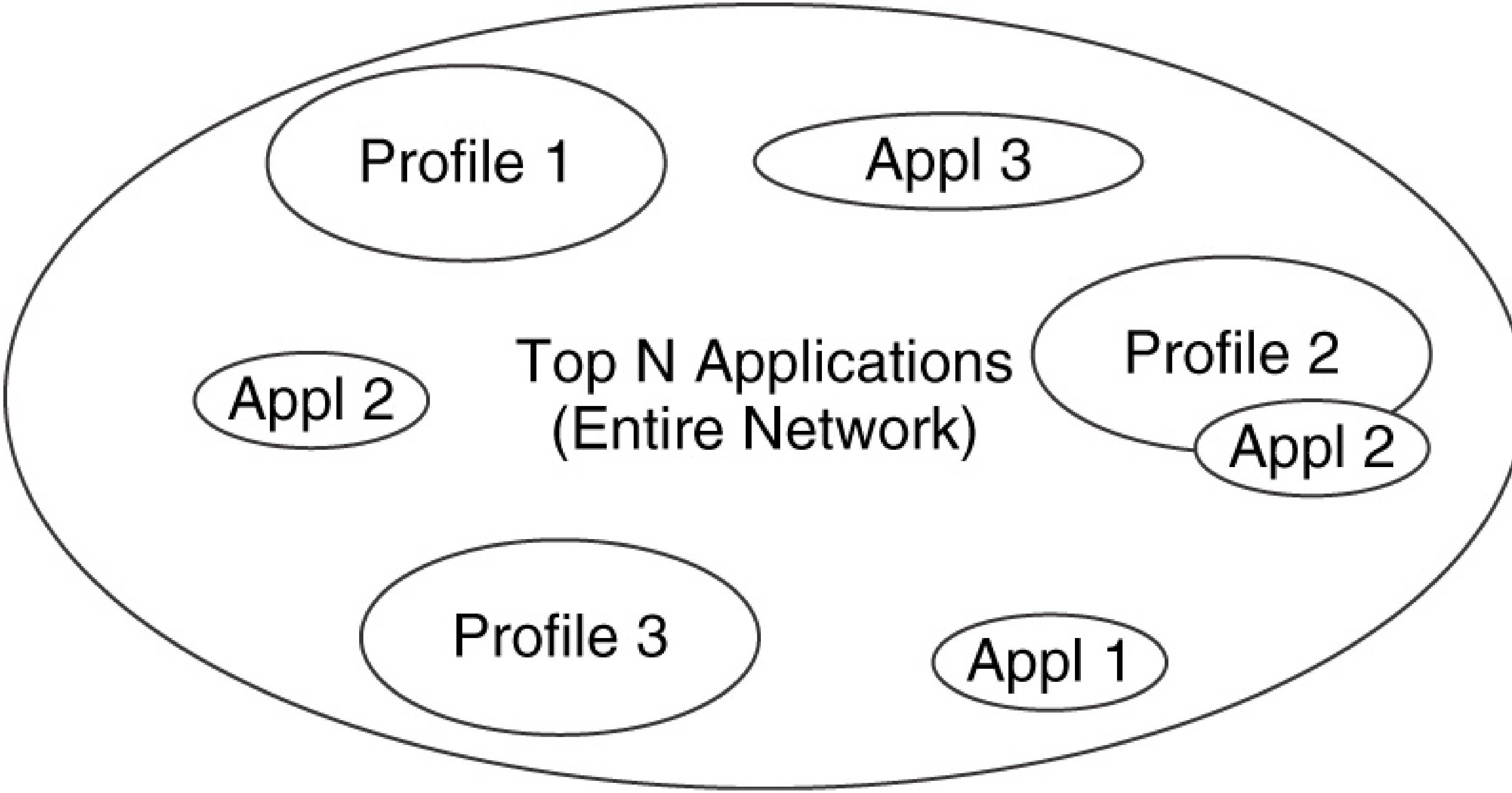
When several flows have identical performance requirements, instead of showing such flows (with requirements) individually, a ***common profile*** can be shown for these flows.



P1- Profile of flows with capacity 100Kb/s; reliability 100%. There are six such flows in this profile

Approach 3: Choosing Top N Applications

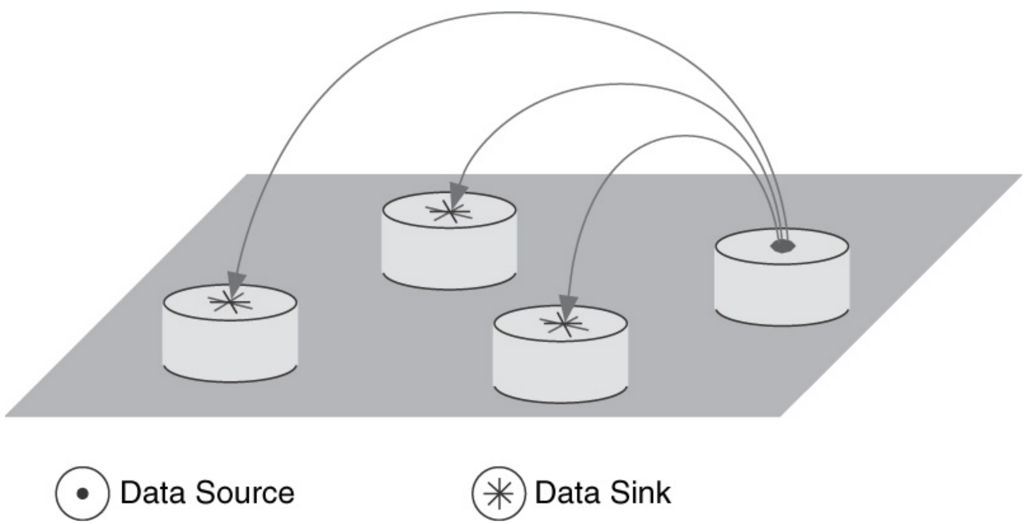
- In general, analyzing flows for all applications on a network for an enterprise with many applications is not time-effective.
- What we do is select applications that represent the most important requirements for that network to do flow analysis.
- If you meet the needs of these applications, you are likely to meet the needs of all applications for that network.
- Examples – Top 3 Applications may be
    - Web browsing
    - Email
    - Database transactions


Profile 1
Appl 3
Top N Applications
(Entire Network)
Profile 2
Appl 2
Appl 2
Profile 3
Appl 1

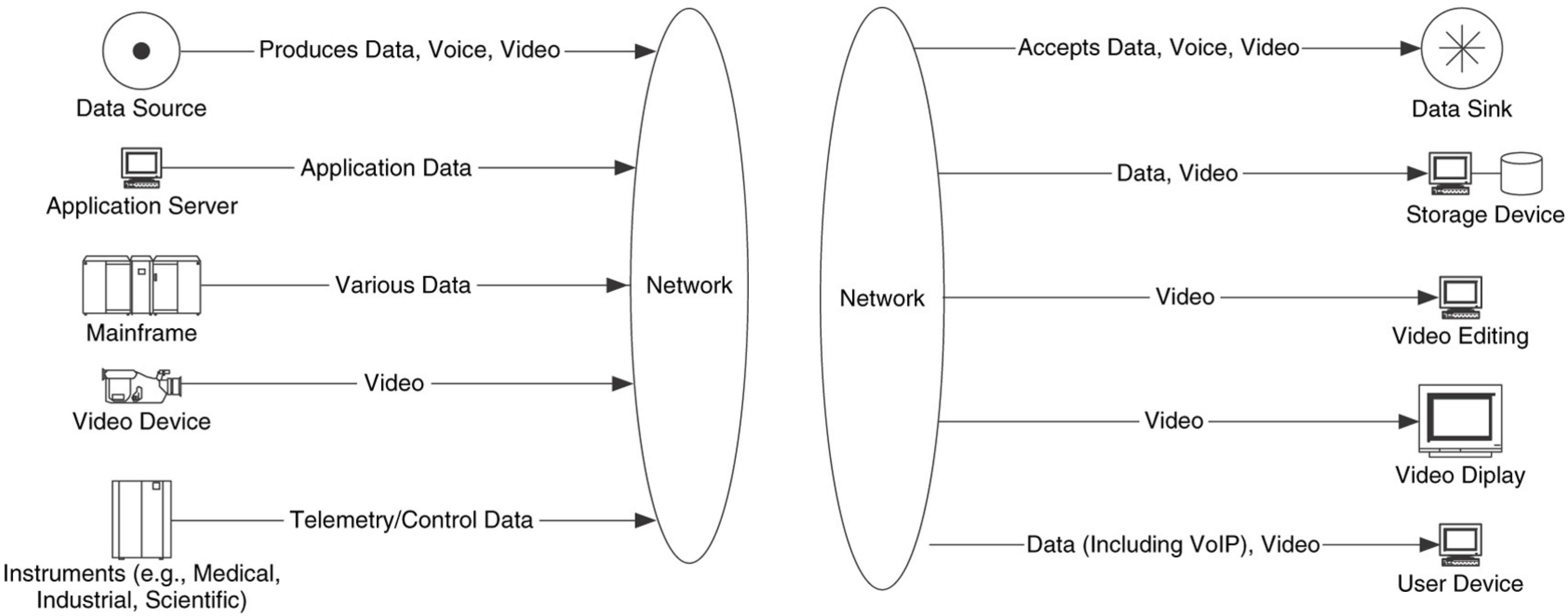
Flow Directionality
Data Source and Sink Notation

- ***Data sources and sinks*** are tools to indicate **directionality** to flows.

- ***Data sources*** (indicated by ⊙) **generate** traffic flows, and ***data sinks*** (indicated by ⊛) **terminate** traffic flows.



Examples of Data Sources & Sinks



Data Sources

Data Sinks

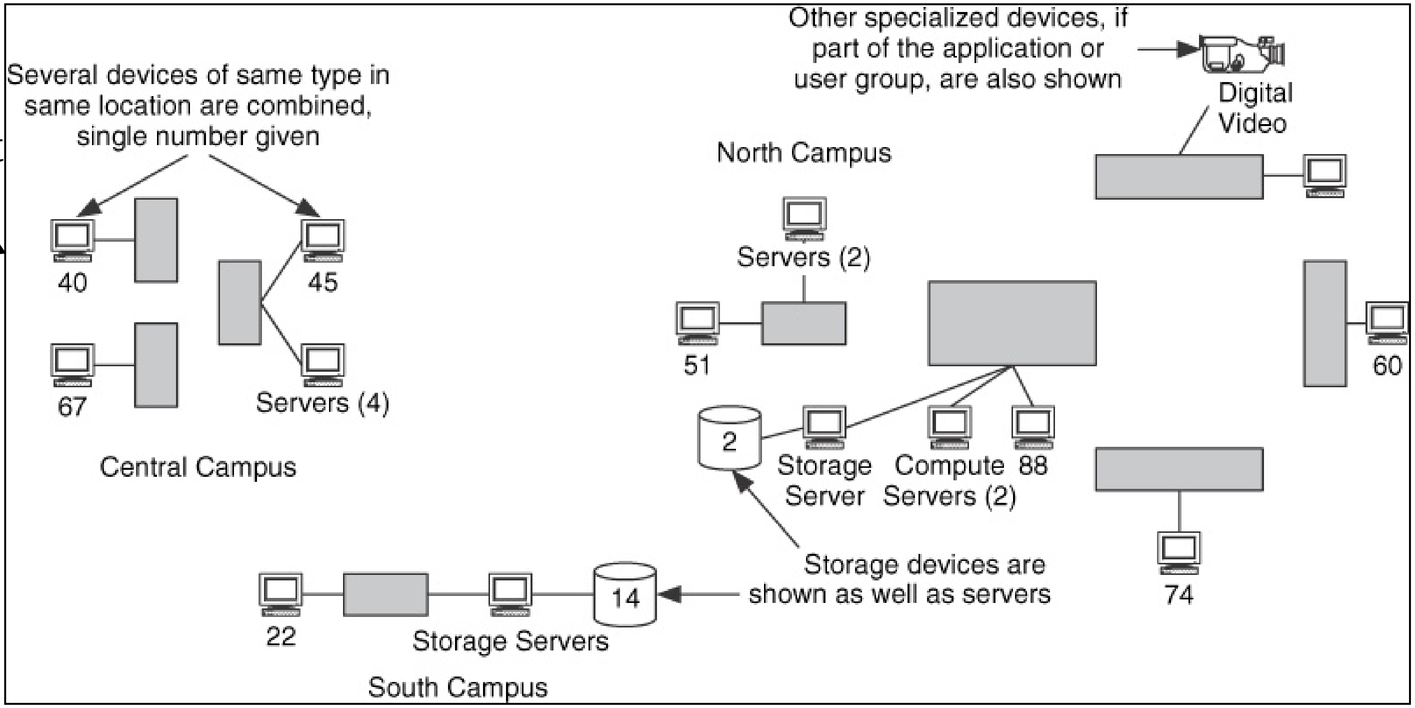
Revisit of Data migration Example W/Source and Sink

Recall

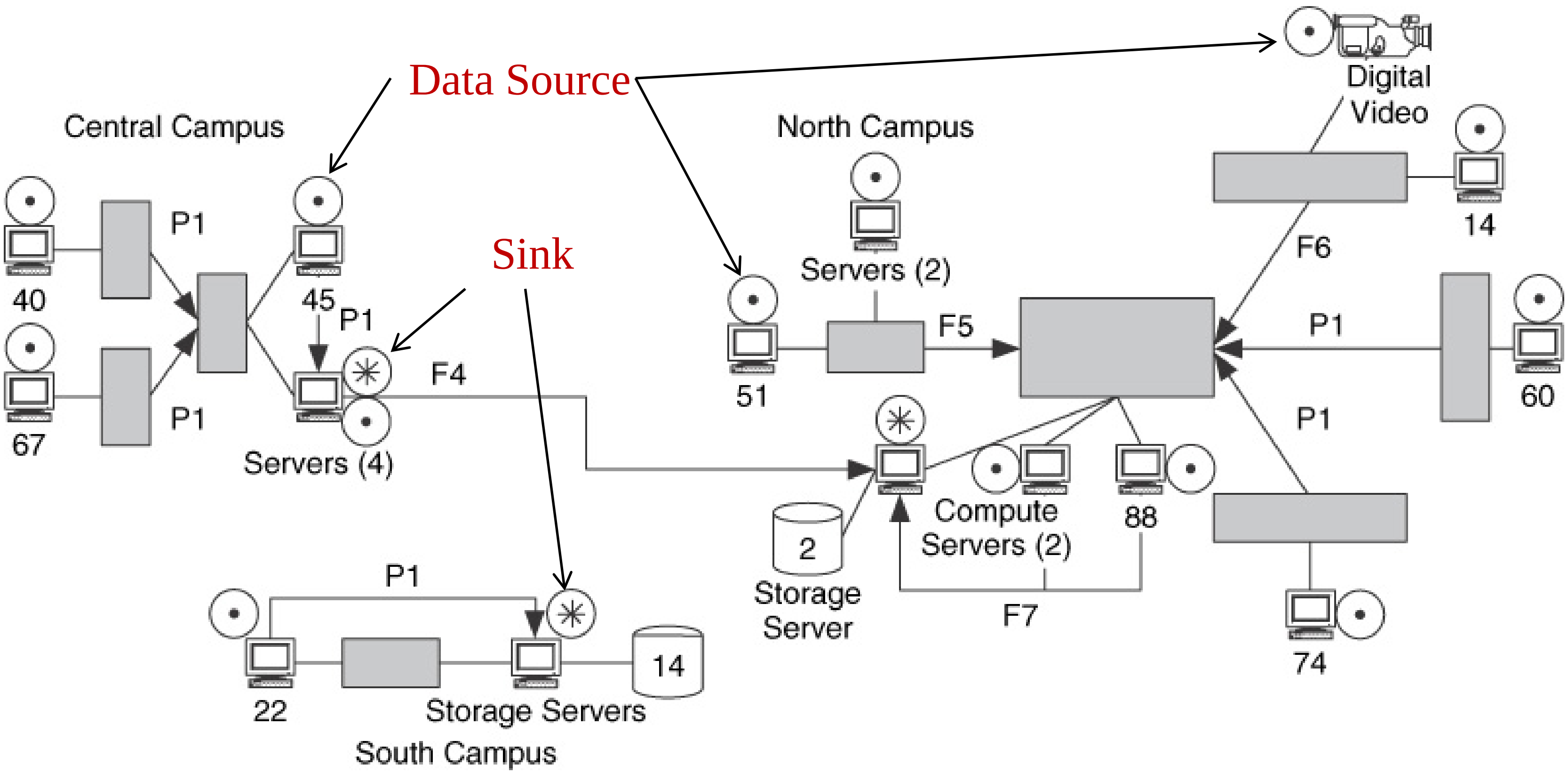
Applications

- Application 1 – Staging data from user devices: Capacity 100Kb/s; delay unknown; Reliability 100%
- Application 1 – Migrating data between servers: Capacity 500Kb/s; delay unknown; Reliability 100%
- Application 2 – Migrating to a remote server: Capacity 10Mb/s; Delay N/A; Reliability 100%

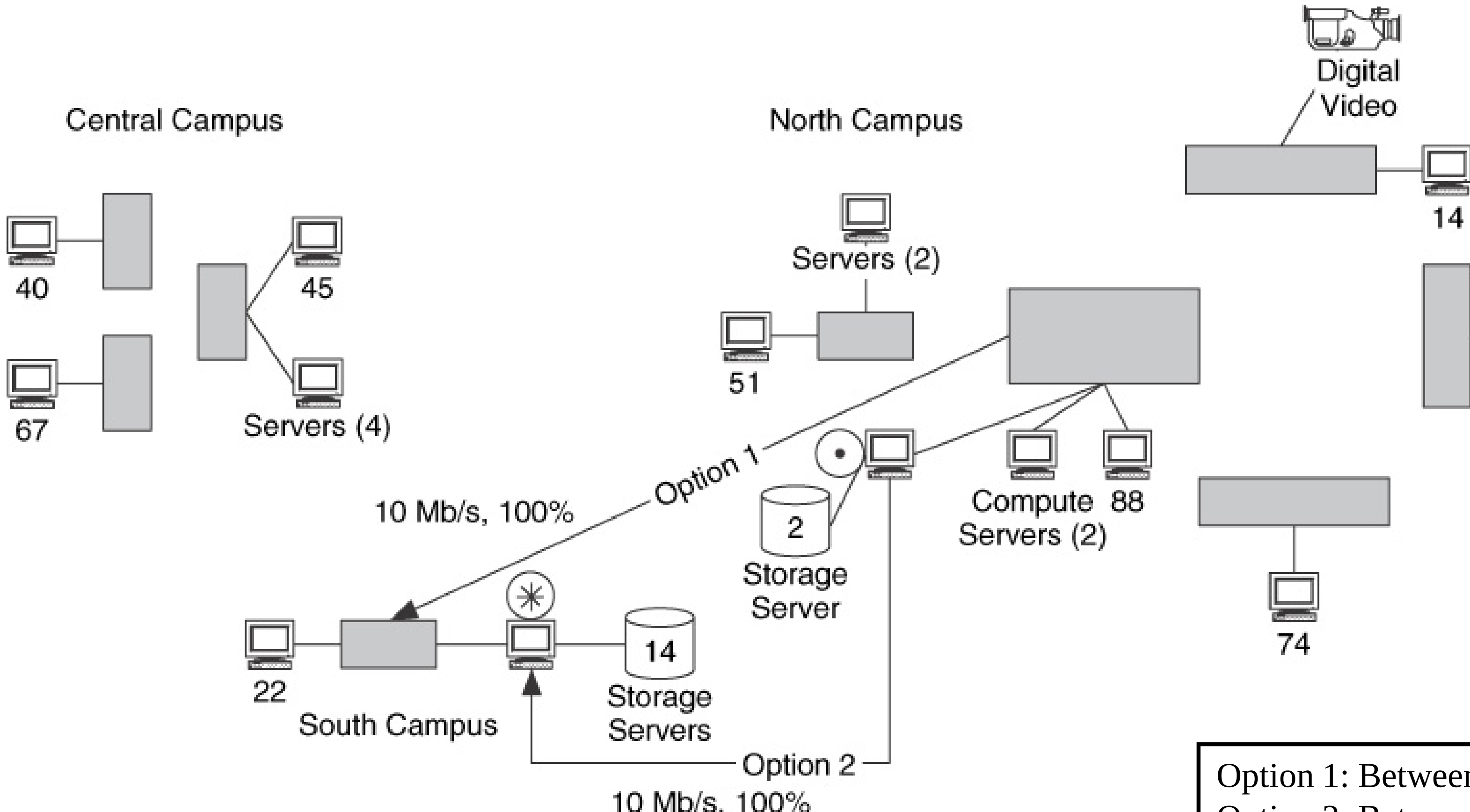
Device Layout



Example Data Migration - W/ Data Sources and Sinks for Applications 1



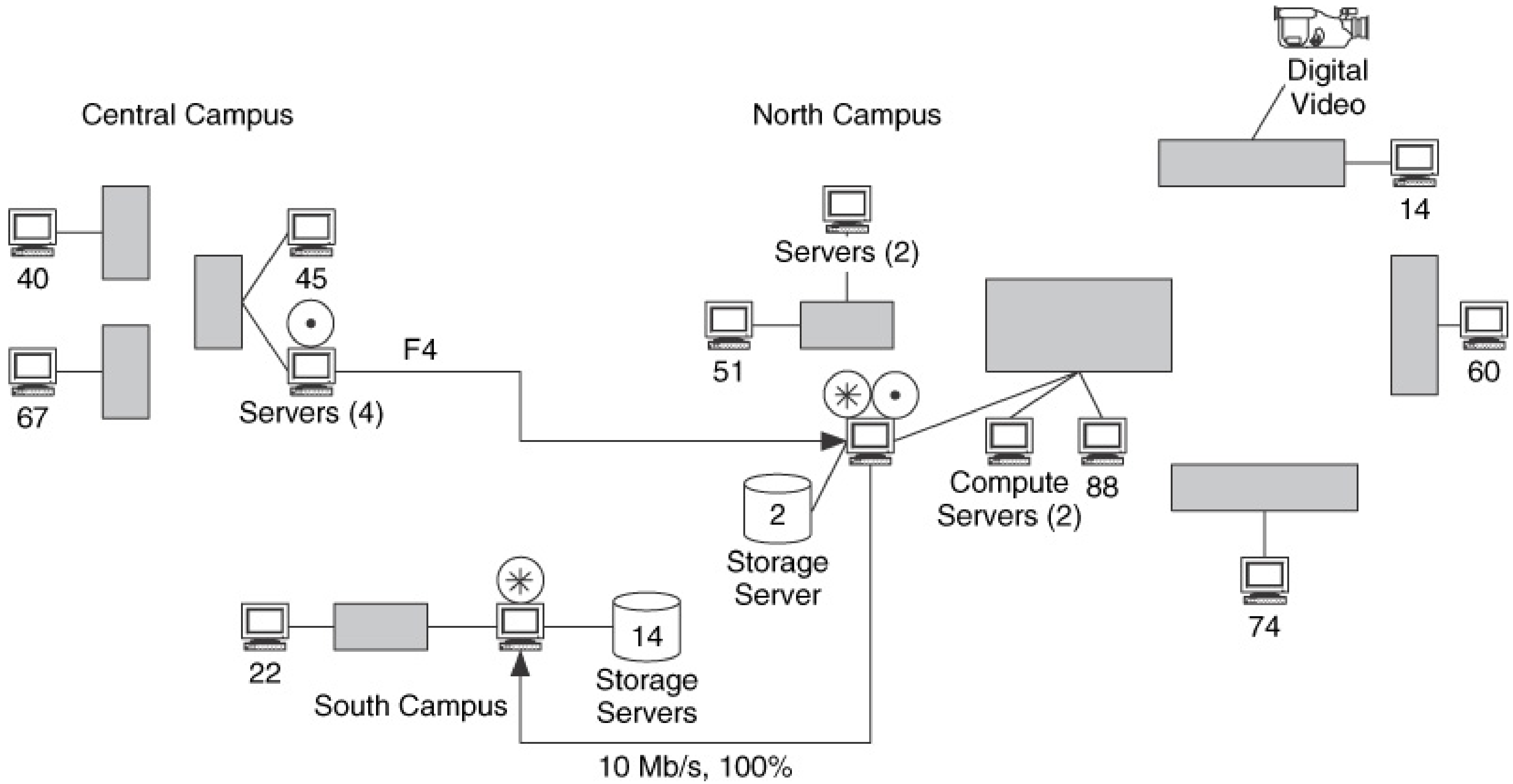
Data Sources Sinks in Application 2
Two Ways to Show (Option 1 and Option 2)



Option 1: Between Buildings
Option 2: Between Devices

Application 2 – Migrating to a remote server :
Capacity 10Mb/s; Delay N/A; Reliability 100%

(Source (Server)-to-Sink (Server)) flows in Data Migration - Option 2 View (Device-to-Device)



Application 2 – Data Migrating to a remote server at South campus from Central and North Campuses (Capacity 10Mb/s; Delay N/A; Reliability 100%)

Flow Models

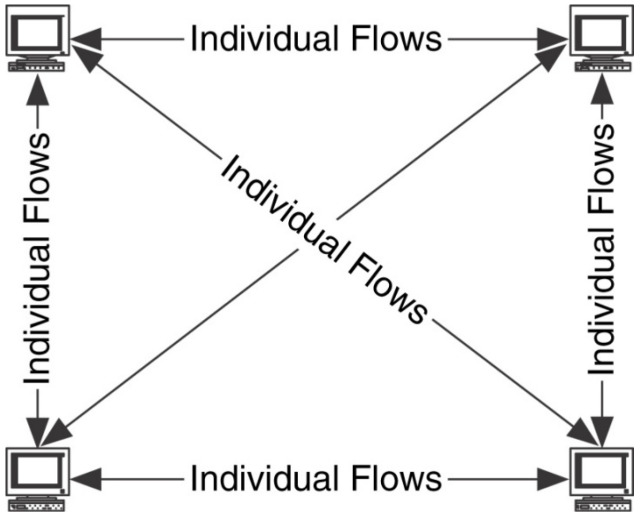
Models to describe flows:

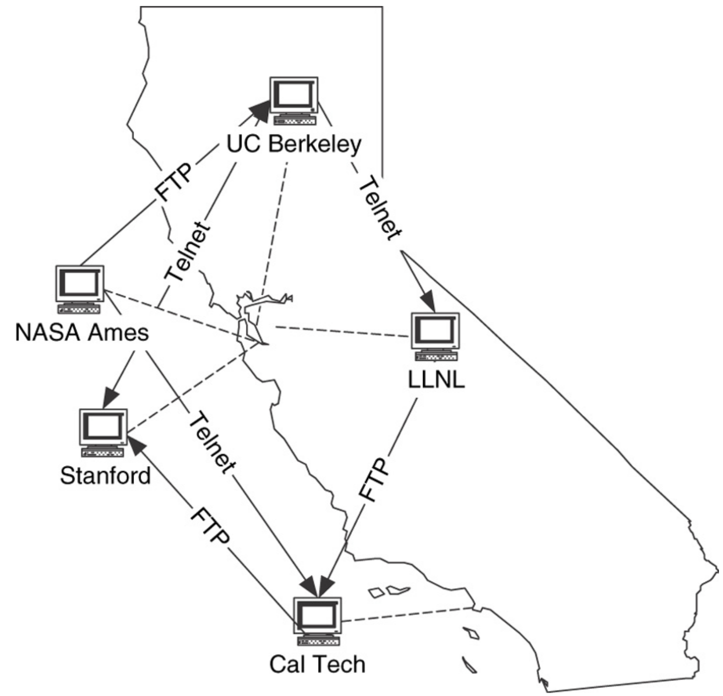
- Peer-to-Peer
- Client-Server
- Hierarchical client-server
- Distributed computing

Peer-to-Peer

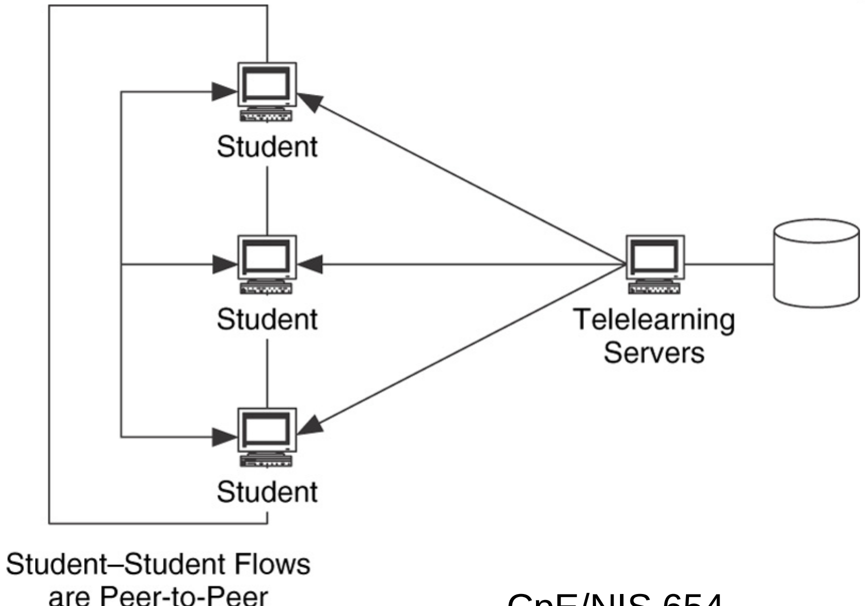
- Example: BitTorrent - Distributing large Files to many users.
- Applications, and devices are equal throughout the network.
- This has two implications:
  - We cannot distinguish between flows in this model. Therefore, either all the flows are critical or none of the flows are critical.
  - The flows are equivalent, so they can be described by a single specification (i.e., profile).

Examples of Peer to Peer Models





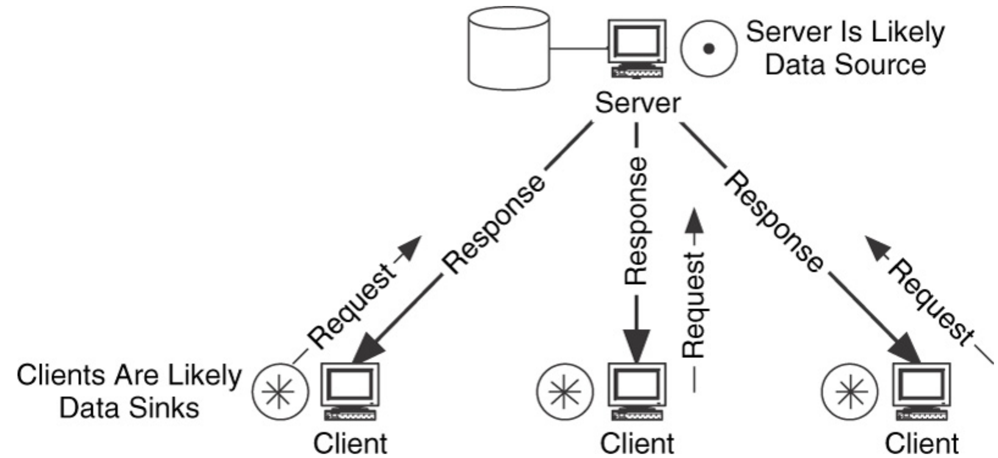
Early Internet

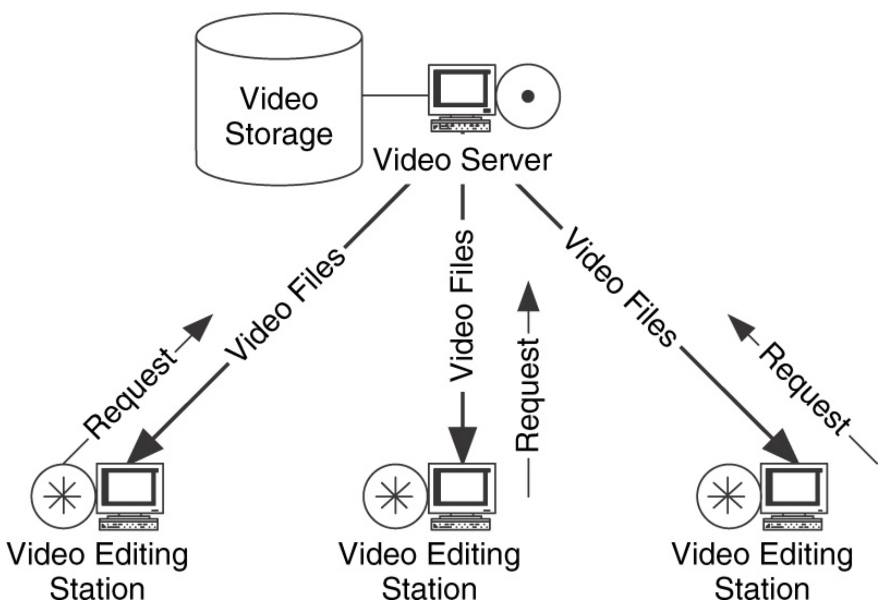


Client-Server Flow Models

Examples:

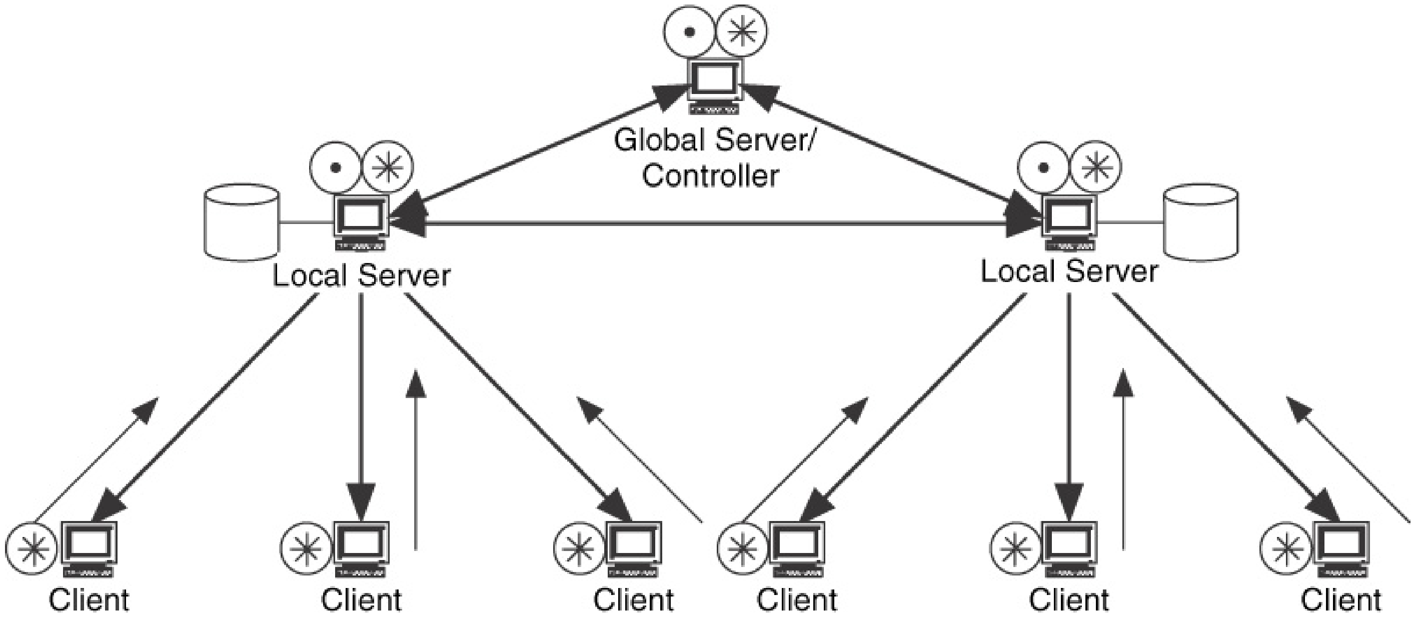
- Internet (FTP and Web Servers)
- Video editing



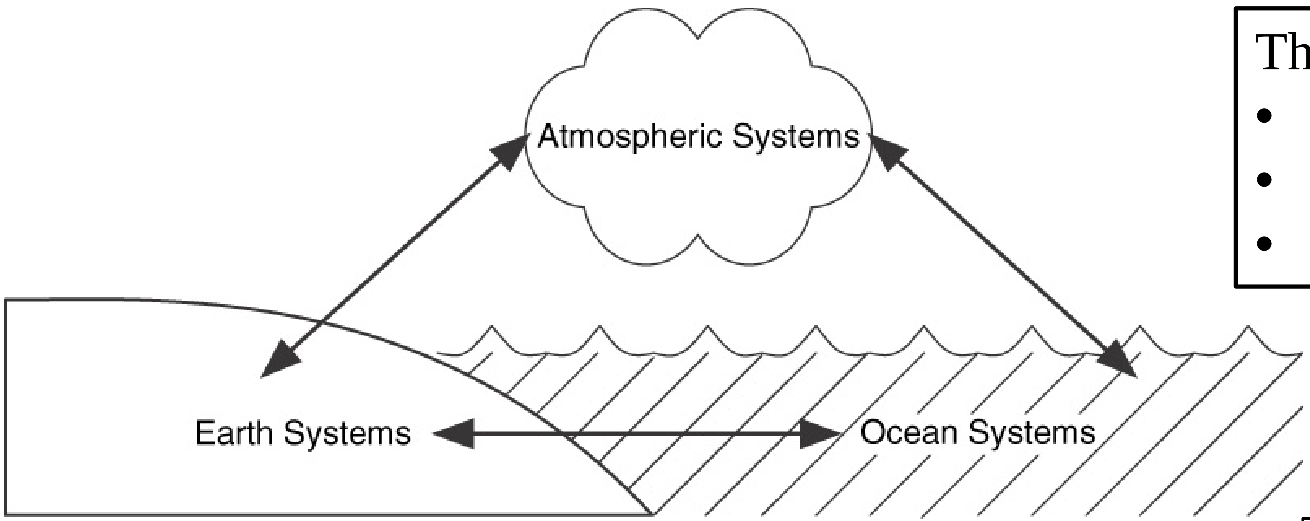


Note sources and sinks

Hierarchical Client Server Model

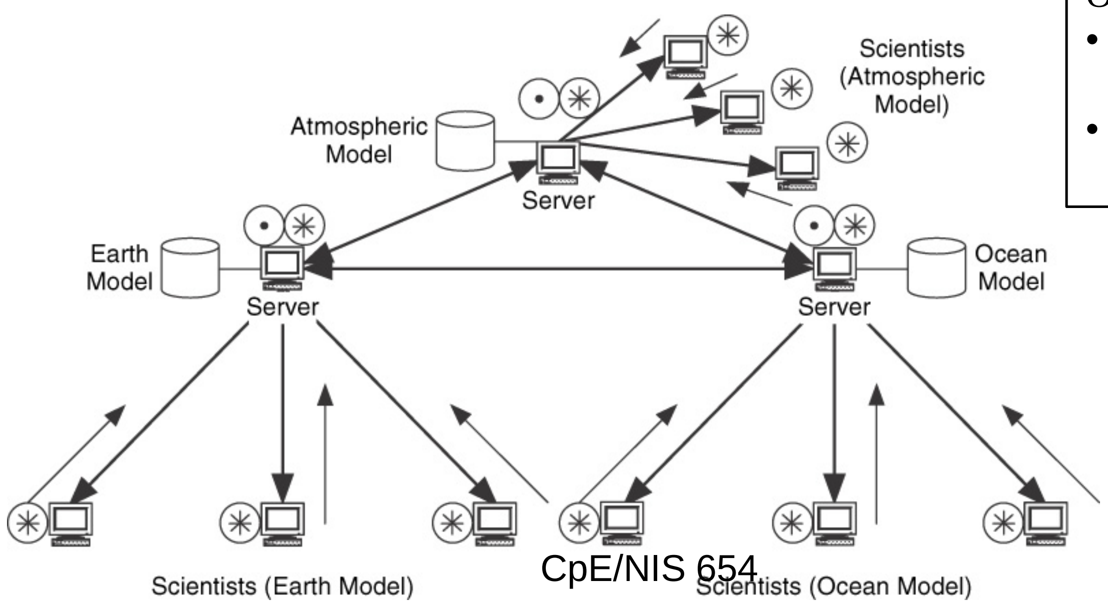


Hierarchical Client Server - Example



Three system simulation

- Atmospheric
- Earth
- ocean



Other examples

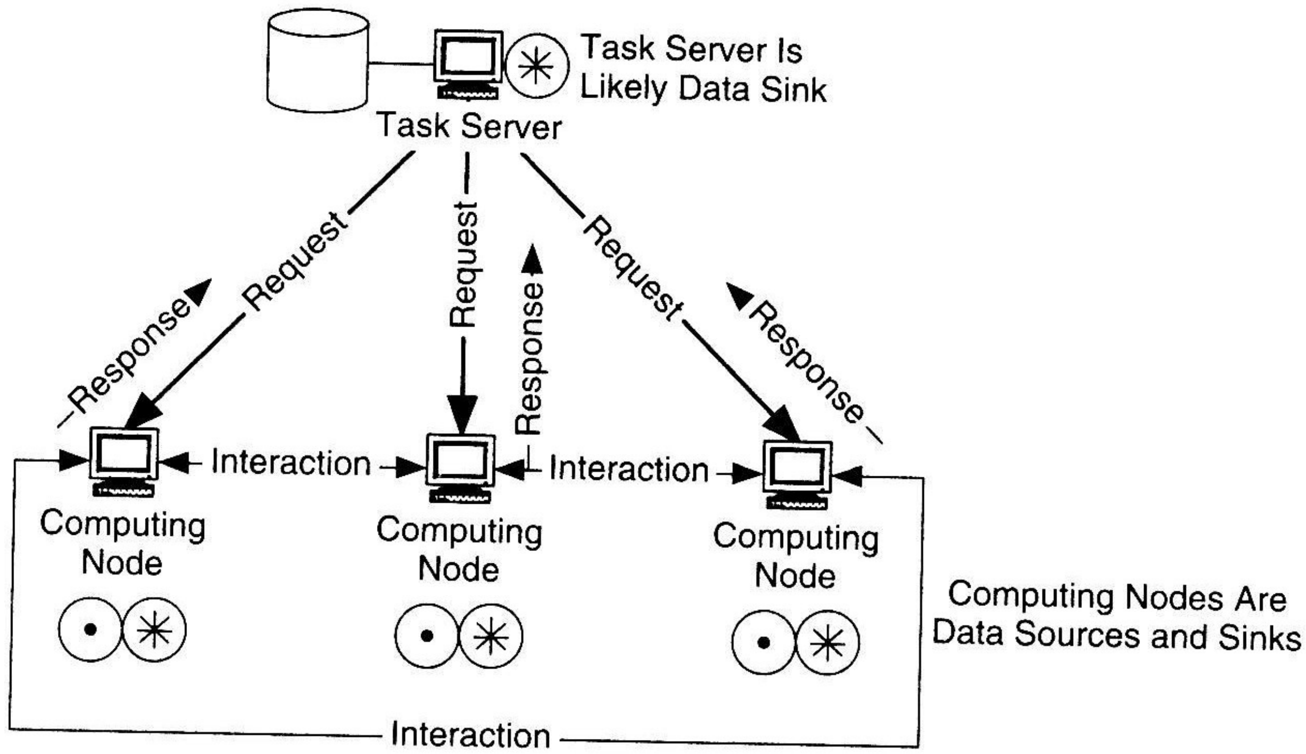
- DNS-Domain Name System
- DHCP-Dynamic Host configuration Protocol

Distributed Computing

In this model, flows may be between:

- A task manager and its computing devices(like a client-server model).
- The computing devices (like a peer-to-peer model).
- The type of model depends on how the distributed computing is done.
- We can make distinctions in the distributed- computing flow model based on the application type.

A Distributed Computing Flow Model



Examples:

- Parallel computing
- Interconnected computing clusters w/ or w/o hierarchy

Flow Prioritization

Flow prioritization to rank flows based on their importance:

- Business objectives
- Performance requirements of the flows (e.g., capacity, delay, RMA, quality of service)
- Security requirements for each flows.
- The numbers of users, applications, and/or devices that a flow serves.

The purpose for prioritizing flows is to determine which flows get most resources and/or which flows get resources first to meet client expectations.

Flow Information from Analysis for Prioritization

Flow ID	Performance Requirements			Number of Users
	Reliability	Capacity	Delay	
F1	N/A	1.2 Mb/s	10 ms	1200
F2	99.5%	100 Kb/s	N/A	550
F3	99.5%	15 Kb/s	100 ms	100
CF1	99.95%	500 Kb/s	100 ms	1750
CF2	N/A	100 Kb/s	100 ms	2100
CF3	N/A	3 Mb/s	100 ms	50

Total Budget for Network Project: $750 K

Budgeting (Prioritization) Based on Number of Users

Flow ID	Performance Requirements			Number of Users	Budget	Priority
	Reliability	Capacity	Delay			
CF2	N/A	100 Kb/s	100 ms	2100	$274 K	1
CF1	99.95%	500 Kb/s	100 ms	1750	$228 K	2
F1	N/A	1.2 Mb/s	10 ms	1200	$157 K	3
F2	99.5%	100 Kb/s	N/A	550	$72 K	4
F3	99.5%	15 Kb/s	100 ms	100	$13 K	5
CF3	N/A	3 Mb/s	100 ms	50	$6 K	6

Total Budget for Network Project: $750 K

Budgeting (Prioritization) Based on Performance Requirements

Flow ID	Performance Requirements			Number of Users	Budget	Priority
	Reliability	Capacity	Delay			
CF1	99.95%	500 Kb/s	100 ms	1750	$375 K	1
F2	99.5%	100 Kb/s	N/A	550	$141 K	2
F3	99.5%	15 Kb/s	100 ms	100	$141 K	2
F1	N/A	1.2 Mb/s	10 ms	1200	$31 K	3
CF2	N/A	100 Kb/s	100 ms	2100	$31 K	3
CF3	N/A	3 Mb/s	100 ms	50	$31 K	3

Total Budget for Network Project: $750 K

The Flow Specification

Flow specification or ***flowspec*** is aggregating flows by their attributes and performance:

- Best effort, predictable, or guaranteed
- Mission critical, rate critical
- Interactive, real time
- Low or high performance

Flow Specs - Type

Flow specifications can be one of three types:

- One part
- Two part
- Multiple

Flow Specification Type	Types of Flows	Performance Description
One-Part	Best-effort requirements individual and composite	Capacity only
Two-Part	Best-effort & predictable requirements	Reliability, Capacity, and Delay
Multipart	Best-effort, predictable, and guaranteed requirements	Reliability, Capacity, and Delay

Flowspec Algorithm

A mechanism to combine flow performance requirements (capacity, delay, and RMA).

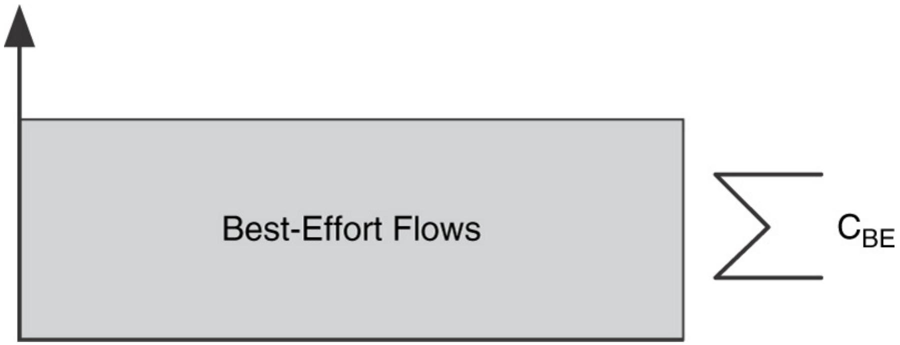
The flowspec algorithm applies the following rules:

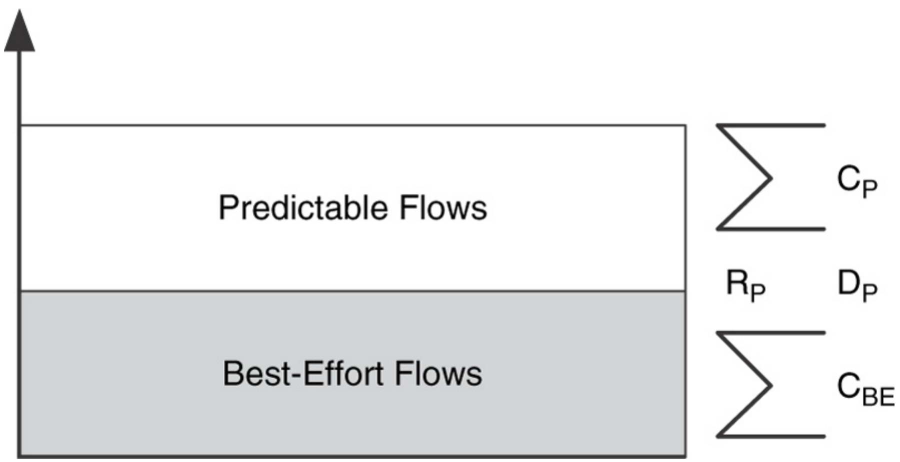
1. Best-effort flows: only capacities are used and aggregated.

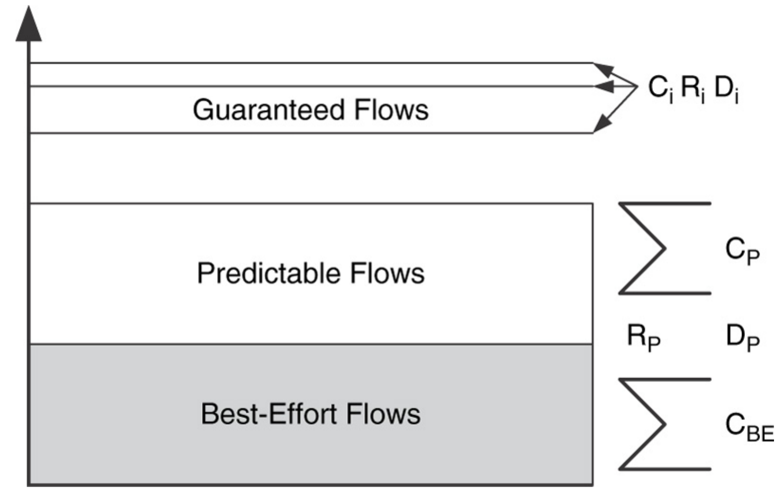
2. Flows with predictable requirements: Performance requirements are combined for each characteristic (capacity, delay, and RMA) to maximize the overall performance of each flow

3. Flows with guaranteed requirements: Individual flows with their specific Performance requirements are used

Part One, Two and Multi Part Flow Spec.







BE; Best Effort
P: predictable
C: Capacity
R: Reliability
D: Delay

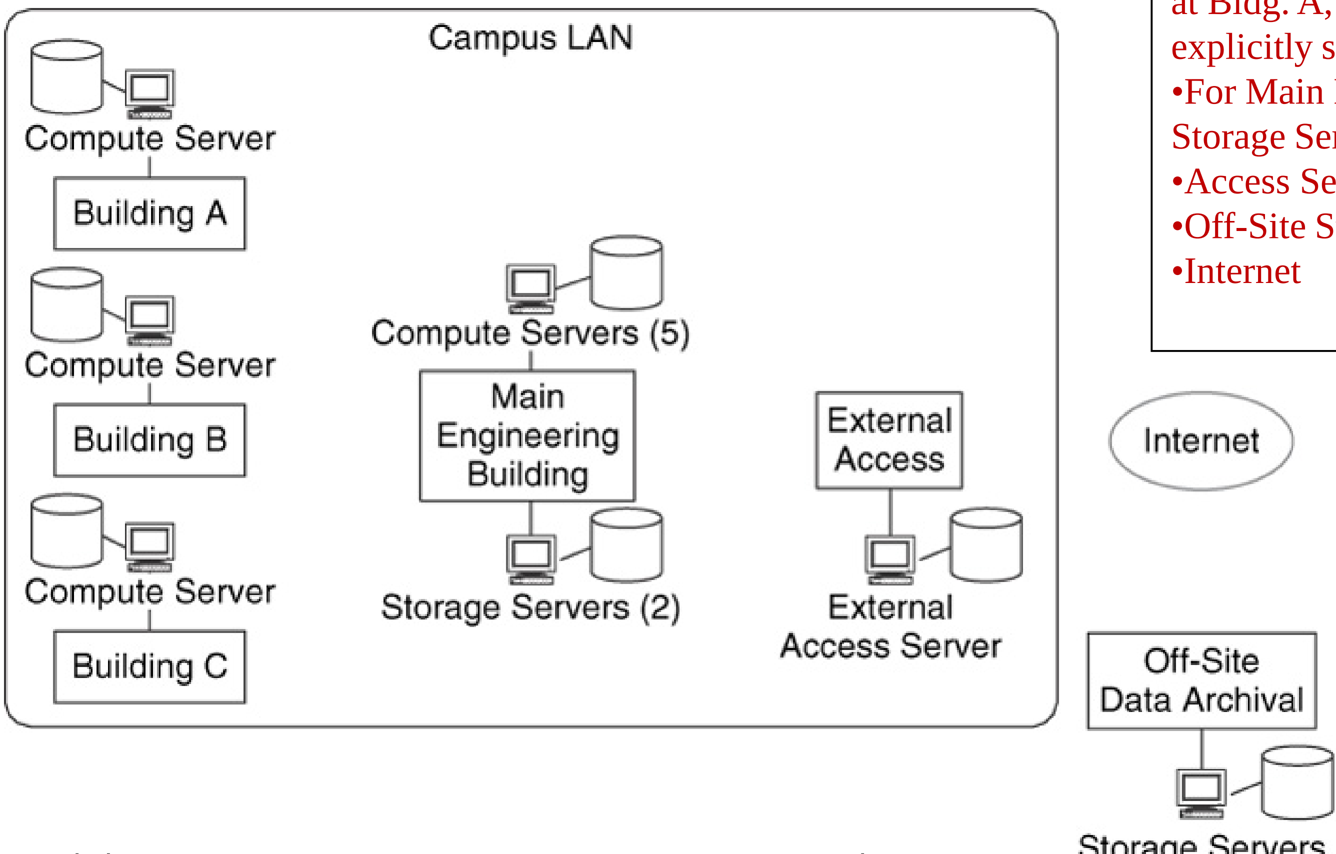
Capacity Vs. Service Plan

- Capacity plan - performance in terms of capacity only, (one-part flowspec) – Relatively easier.
- Service plan - network performance in sets of capacity, delay, and RMA, (two-part and multi-part flowspecs.) – Harder.
- Capacity and Service plans are written descriptions of performance required and described in the flowspec.

An Example of Flow Spec Development
Network for computing and storage management

In the rest of the slides, we demonstrate how one could go about developing flow specs for a project

Building and Device Map Layout From Requirement Analysis



Note the layout:
Several Buildings

- Compute Servers and Storage Servers at Bldg. A, B, and C.(storage server not explicitly shown for A, B, C buildings)
- For Main Building, both Compute and Storage Servers are shown
- Access Servers for External Access
- Off-Site Storage Servers
- Internet

An Example of Flow Spec Development (continued)

Flow Types from Requirements Analysis

Four types of flows were determined from the requirements analysis:

Flow Type 1: Flow among high-performance compute and storage servers in A, B, C, and Main in interactive and batch modes:

1. Among compute servers to sync files
2. Between compute servers and their storage serves for interactive updates
3. Among compute servers and their storage servers as final data sets

Flow Type 2: Data migration from compute and storage servers to the Main Engineering storage servers.

1. File Updates
2. Final Data sets

Flow Type 3: Data migration from Main Engineering storage server to external access server.

Flow Type 4: Data flow among external access server, off-site data archival and External Users for access via Internet by outsiders.

An Example of Flow Spec Development (continued)

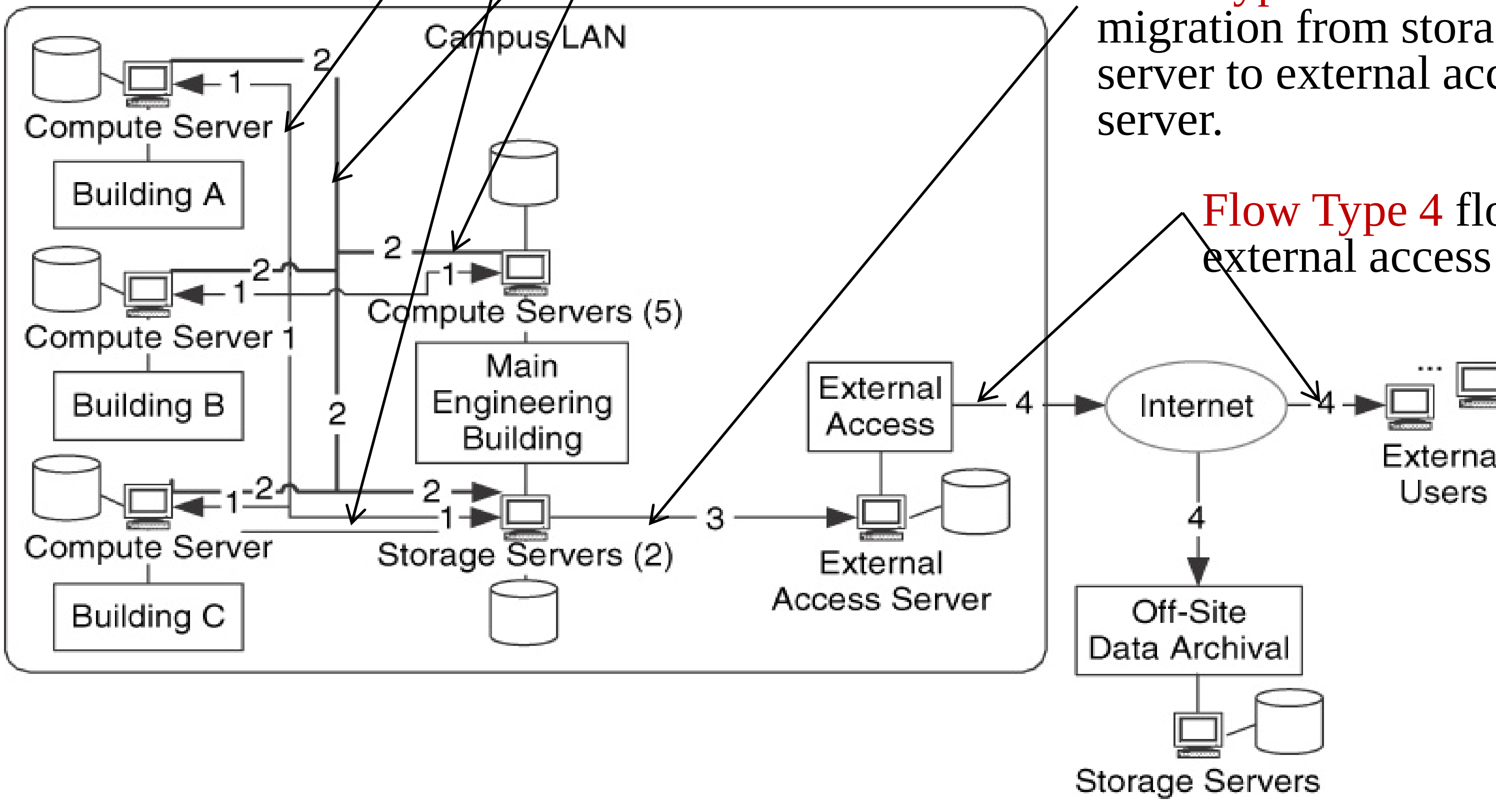
Maps with Flow Types Are Now Added to Devices Layout

Flow Type 1: Flow among high-performance compute and storage servers

Flow Type 2: Data migration from compute and storage servers to the Main Engineering storage servers.

Flow Type 3: Data migration from storage server to external access server.

Flow Type 4 flow among external access server/users



An Example of Flow Spec Development (contd.)

Capacities Requirements of Flow Type 1

Type 1 Flow is among high-performance compute and storage servers in bldgs.

Flow Type 1 requirements state that the computing application runs in interactive and batch modes, from about 10 minutes to several hours generating data files between servers.

•**Synchronization files** of 1 to 2 MB (Megabytes) requiring synchronization at human response time (HRT:100ms).

•**Interactive update files** of 10 to 100 MB requiring updates at 1 second response time.

•**Final data set files** of 500 MB to 1 GB requiring 10^2 to 10^4 seconds (minutes to hours).

•**Users expect to have up to two tasks running concurrently.**

From this information, we can estimate a range for capacity performance requirements for Flow Type 1.

An Example of Flow Spec Development (continued)

Flow Type 1 From requirements Analysis

Computing Applications run in interactive or batch mode from 10 minutes to several hours generating the following Type 1 traffic:

- **Sync files of** 1 to 2 MB (synchronization file), requiring synchronization on the order of human response time (HRT) (100ms).

  (1 to 2 MB)(8 b/B)(2 concurrent tasks)/10^{-1}s

  = 160 to 320 Mb/s

- **Update files:** From 10 to 100 MB (interactive updates), requiring updates on the order of 1 second.

  (10 to 100 MB)(8 b/B)(2 concurrent tasks)/1 s

  = 160 Mb/s to 1.6 Gb/s

- **Final data sets:** 500 MB to more than 1 GB for final data sets, this requires minutes to hours (10^2 to 10^4 seconds). Calculate for best and worst case:

  (500 to 1000 MB)(8 b/B)(2 concurrent tasks)/(10^2 to 10^4s)

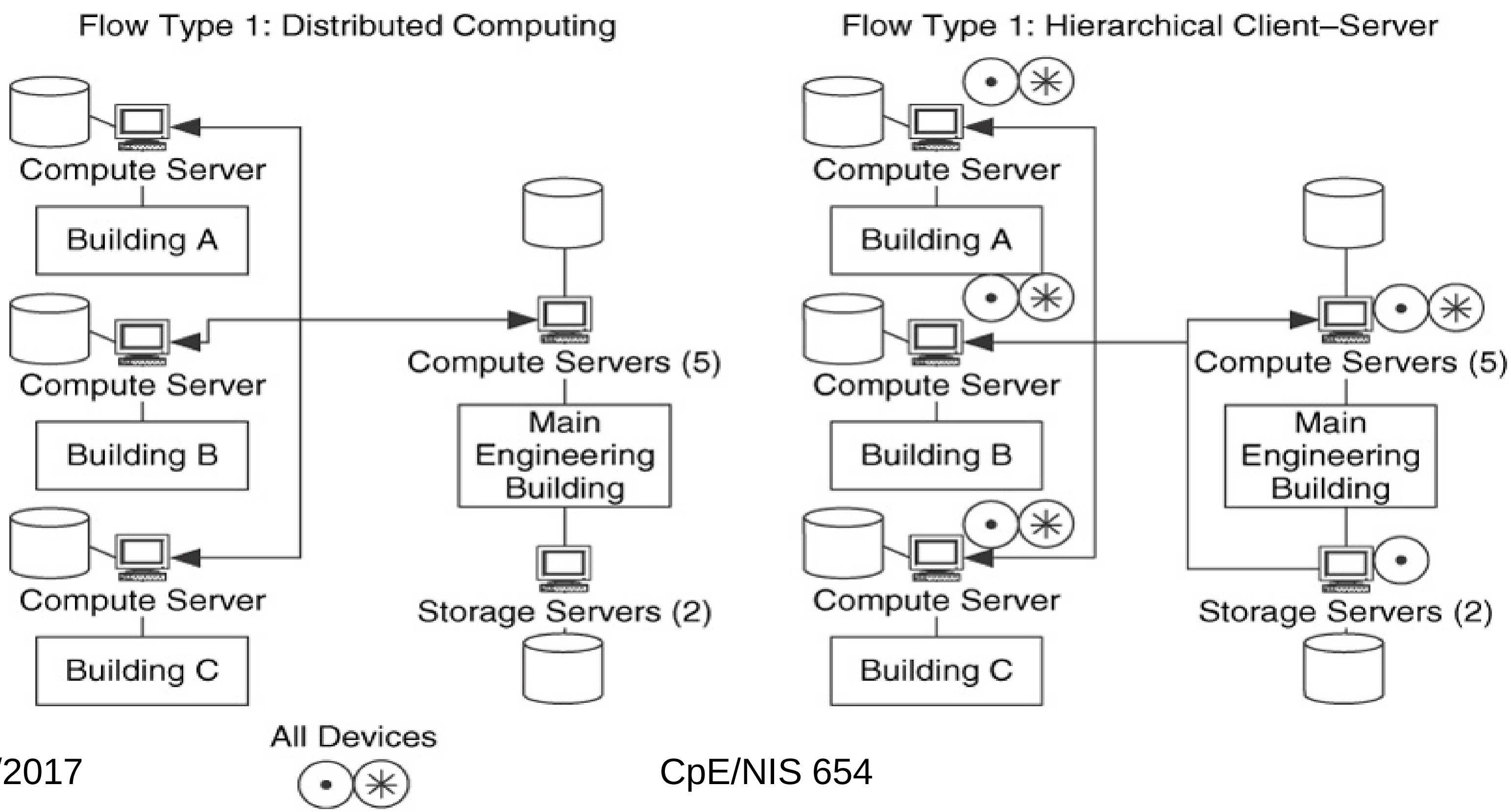
  $= (500 \times 10^6 \times 8 \times 2/10^4)$ to $(10^9 \times 8 \times 2/10^2)$

  = 800 Kb/s to 160 Mb/s

An Example of Flow Spec Development (continued)

For Flow Type 1 Consider Possible Architecture Models

- Distributed- computing flow model if compute servers from building A through C and Main Engineering act as synchronized peers.
- Hierarchical client- server flow model if the Main Engineering compute server acts as a server for the compute servers in buildings A, B, and C.
- Depending on the model, the flow pattern will vary



An Example of Flow Spec Development (continued)

Flow Type 2

Data migration from compute and storage servers to the Main Engineering storage servers

- Data are stored at the storage servers in Main Engineering Building (interactive updates, final data sets, and extracts, (selected subsets of final data set), usually every few hours.
- The delay characteristics of these flows are much less strict, ranging from 10 seconds to 10^4 seconds (few hours).

Update files: (10 to 100 MB)(8 b/B)/(10 to 10^4s)

$$= (10 \times 10^6 \times 8/10^4) \text{ to } (100 \times 10^6 \times 8/10^1)$$

= 8 Kb/s to 80 Mb/s

Final data sets: same data size as for flow type 1 which is moved to the main building, that is 500 MB to more than 1 GB for final data sets, this requires 10^2 to 10^4 seconds (minutes to hours).

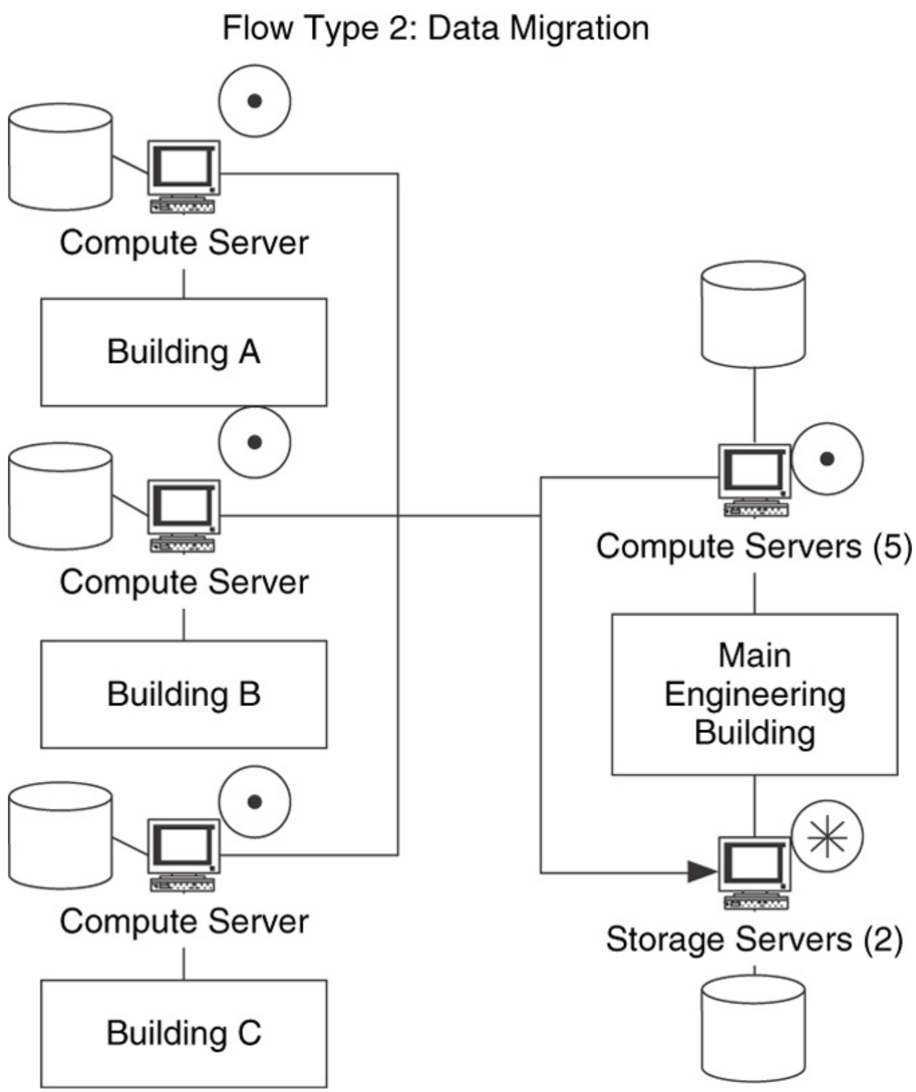
(500 to 1000 MB)(8 b/B)(2 concurrent tasks)/(10^2 to 10^4s)

$$= (500 \times 10^6 \times 8 \times 2/10^4) \text{ to } (1000 \times 10^6 \times 8 \times 2/10^2)$$

= 800 Kb/s to 160 Mb/s

An Example of Flow Spec Development (continued)

Flow Model for Flow Type 2 with Sources and Sinks



Data is pushed from each of the compute and storage servers, including the ones in Main Engineering Building to the Storage Server in the Main Engineering Building.

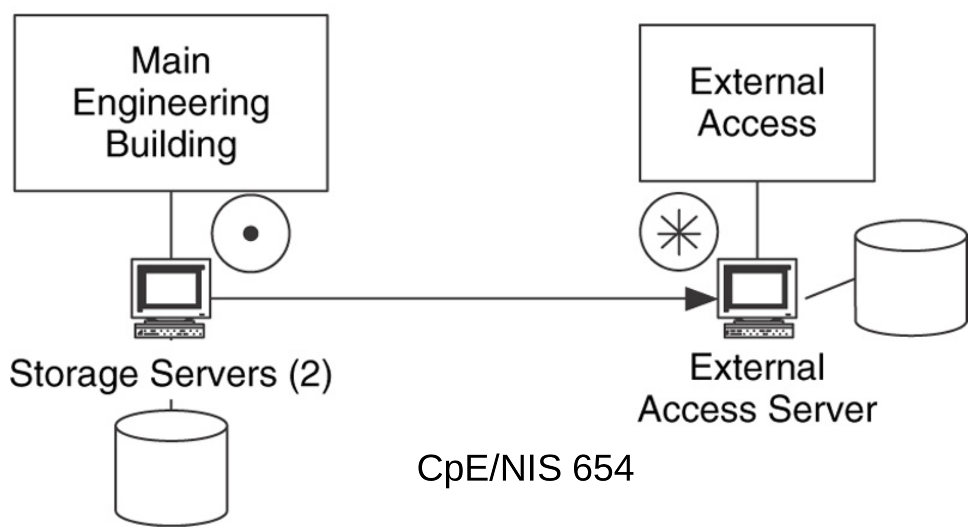
An Example of Flow Spec Development (continued)

Flow Type 3

Data migration from storage server to external access server.

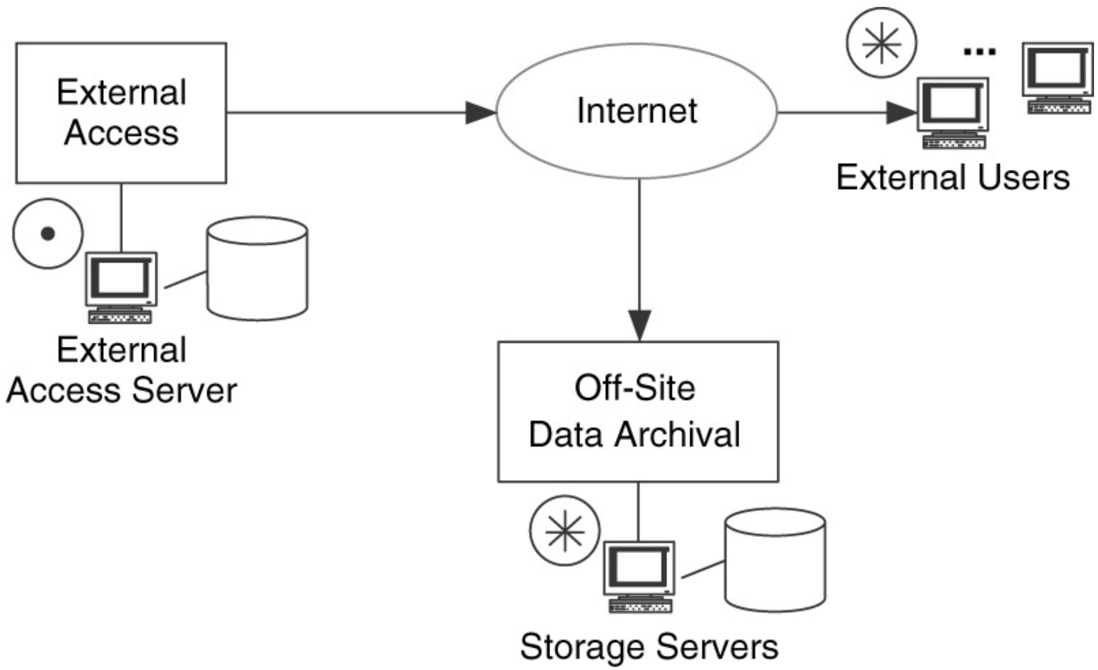
- Flow Type 3: Full data sets (GBytes) and extracts of the data sets are migrated to the external access server.
- Extracts are approximately 80% of the size of a full data set (80% of 1GB). Data sets are migrated hourly (3600 seconds or so).
- So, Full data sets = GBytes and extracts of the data (80% of 1GBytes) = 800MBytes
- Type 3 Flow rate is: (1000 MB + 800 MB)(8 b/B)(4 compute servers)/(3600s) = 16 Mb/s
- Note that this traffic, Servers in the Main Engineering building are the data sources and External Access Server in the data sink.

Flow Type 3: Data Migration



An Example of Flow Spec Development (continued)

Flow Type 4: Data flow among external access server, off-site data archival and External Users for access via Internet by outsiders.



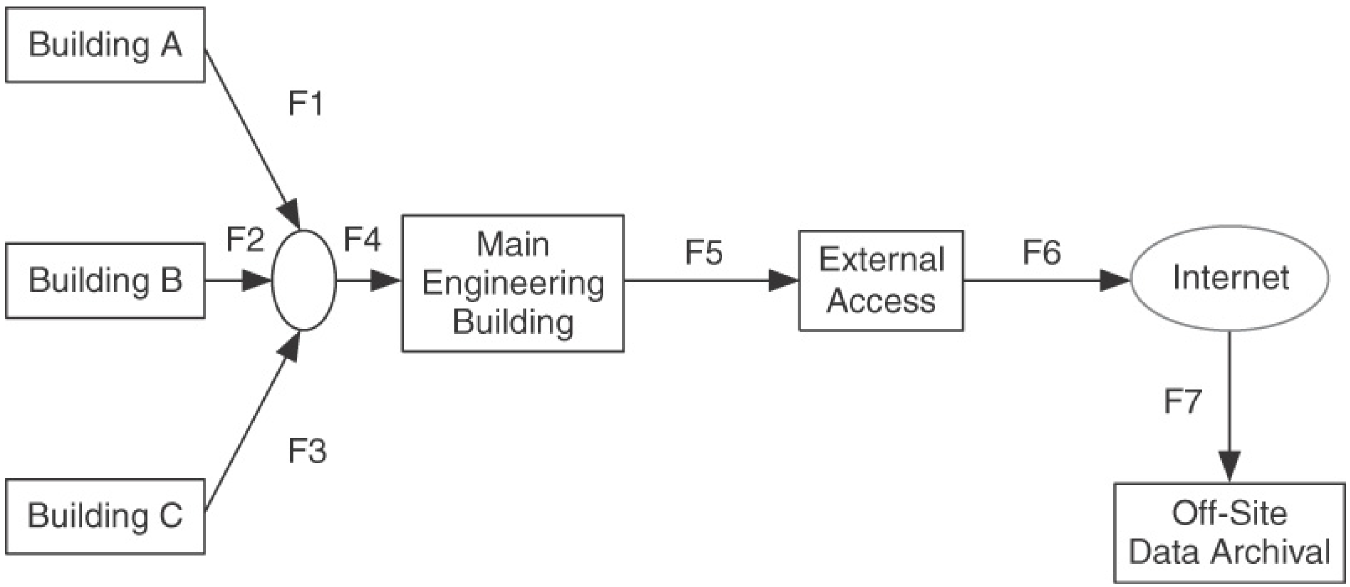
Note for this flow a client-server flow model exists between external users of the data, including off-site archival, and external access server.

•External Access Server is a **Source**

•External Users and Off-site Storage Server are **Sinks**

An Example of Flow Spec Development (continued)

Overall Flow Map with Aggregation



Note that is this figure:

•Flows F1, F2, F3 consist of Type 1 and Type 2 flows, and will have same performance requirements

•F4 is aggregate of flows 1,2,and 3 (flow types 1 and 2)

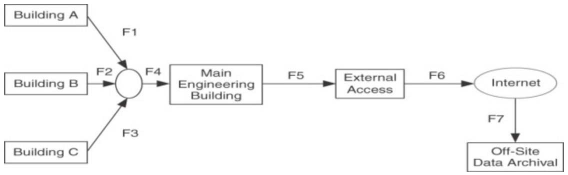
•F5 consists of flow Type 3

•Flows 6 and 7 consist of flow type 4 (Internet Access and off-site archival for F6, and off-site archival for F7)).

An Example of Flow Spec Development (continued)

Performance Requirement Matrix for the Network

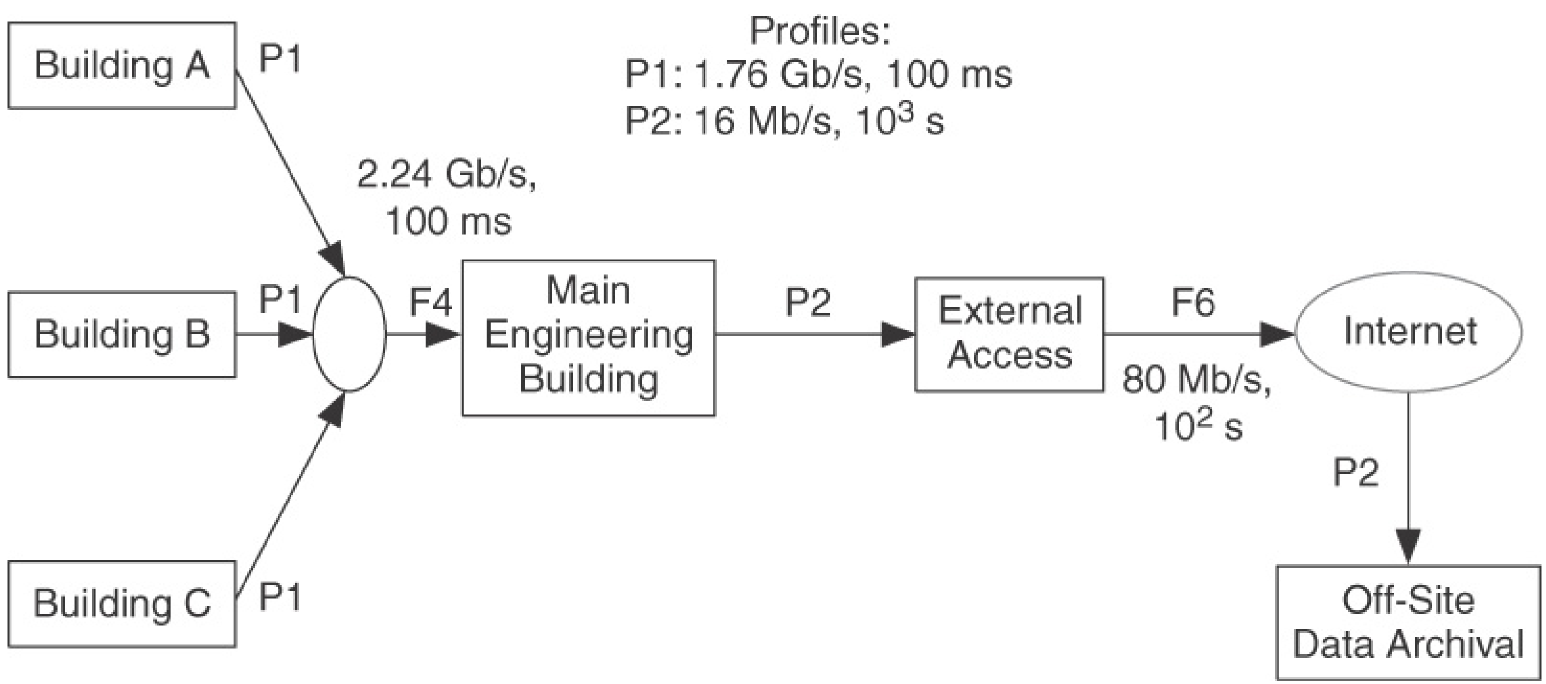
- Combine flows by type for each segment of the network
- In combining, select the strictest requirement (maximum capacity, and minimum delay.
- Do this for each segment to create a performance matrix for the network.
- Note to calculate F4:
  - Type 1: 1600 Mbps; 100 ms delay
  - Type 2: Update files is 4 times individual flows: 80x4 = 320Mbps, 10 second delay. For final data sets, it is 160x4=640Mbps with 100 second delay. Thus performance requirements for F4 for Type 2 is 640Mbpa, 10s delay.
  - Composite requirement for F4 then is 1600+640=2240Mbps, 100ms delay
- F5 is flow type 3 and is as calculated before: 16 Mbps, 100 seconds



Flow ID	Performance Requirements	
	Capacity (Mb/s)	Delay (ms)
F1: Flow Type 1		
Synchronization Files	320	100
Update Files	1600	1000
Final Files	160	10^5
Result for Flow Type 1	1600	100
F1: Flow Type 2		
Update Files	80	10^4
Final Files	160	10^5
Result for Flow Type 2	160	10^4
Result for F1	**1760**	**100**
Result for F2	**1760**	**100**
Result for F3	**1760**	**100**
F4: Flow Type 1	1600	100
F4: Flow Type 2		
Update Files	320	10^4
Final Files	640	10^5
Result for Flow Type 2	640	10^4
Result for F4	**2240**	**100**
Result for F5	**16**	**10^3**
Result for F6	**80**	**10^2**
Result for F7	**16**	**10^3**

An Example of Flow Spec Development (continued)

A Graphical representation of Flows W/ Profiles



- F5 (16Mb/s) is flow from main Engineering to external server and is the same from External server to the off-site data archival. This is Profile P2 (Flow F5 and F7).
- F6 (80Mb/s) consists of F5 (16Mb/s) and internet traffic (64Mb/s).