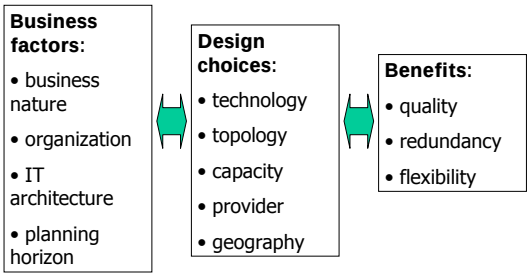
NETWORK DESIGN

- **design choices**
- **queueing theory**
- **business factors**

Network Strategy



Design Choices

- technology
- topology
- capacity
- provider -- public / private network
- geography

Topology

- single vs multi-layer network
  - number of nodes
  - number of paths
- hub / switch locations
- paths

Geography

- technology
  - availability
  - quality
  - supporting services
- regulation
  - monopoly/competition
- cost

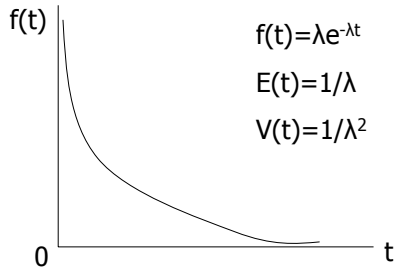
Capacity: Queueing Theory

- demand is uncertain
- capacity is costly
- A/B/c/K/p
  - arrival distribution
  - service distribution
  - number of servers
  - buffer size
  - population

M/M/1 Model: Assumptions

- exponential distribution of time between arrivals (A = M): mean time between arrivals = $1/\lambda$
- exponential distribution of service time (B = M): mean service time = $1/\mu$
- c = 1 server
- K = unlimited buffer
- p = infinite population

M/M/1: Exponential Distribution



$f(t)=\lambda e^{-\lambda t}$

$E(t)=1/\lambda$

$V(t)=1/\lambda^2$

M/M/1: Performance Measures

- utilization rate, $\rho = \lambda/\mu$
- number of jobs in queue, $L_q = \rho^2/[1-\rho]$
- number of jobs in system (in queue or process), $L = \rho/[1-\rho]$
- Little's Formula
  - average waiting time, $W_q = L_q/\lambda$
  - average waiting & service time, $W = L_q/\lambda + 1/\mu = 1/(\mu-\lambda) = L/\lambda$

M/M/1: Example

- mean time between arrivals = 500 ms
- mean service time = 475 ms
- utilization = …
- average time = …
- If reduce service time to 400 ms, what is effect on average time?

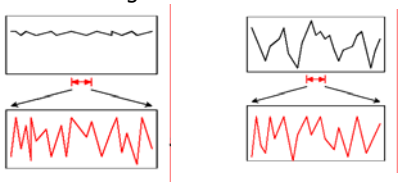
M/M/c/c (Erlang B)

Expected traffic volume				
Channels	Probability of blocking			
	0.01%	0.05%	0.1%	1%
5	0.45	0.65	0.76	1.36
10	2.26	2.80	3.09	4.46
15	4.78	5.63	6.08	8.11
20	7.70	8.83	9.41	12.0

Aggregation

- How to plan for larger scale of traffic?
- Contrasting views:

smoothing fractal



Packet-Switched Network: Kleinrock Approximation

- if
  - packet lengths are exponentially distributed
  - arrivals of new packets at each node are independent Poisson processes
  - service times are independent
- Then queues are independent M/M/1
  - numbers of packets and delays are independent

More General Models

- non-exponential arrival
- non-exponential service
- multiple servers
- limited buffer
- varying customer population

Capacity: Decision Variables

- server capacity
- buffer capacity
- compare:
  - impact on average waiting & service time
  - marginal cost

Redundancy

- service providers
- paths
  - physical route
  - cable / satellite
- pricing basis
  - subscription
  - usage

Singapore-Japan: Physical Route

- until 2001, only one link (APCN1) – so, Sept 1999 Taiwan earthquake disrupted communications
- subsequently, additional 10Gbps link (APCN2)

Case: AT&T Network Design

- switch – dual processor
- signal transfer points
  - deployed in pairs
  - each at 50% capacity
- network control points
  - dual processors
  - back ups
- power supply: battery back-up

Flexibility

- private vs public network
- fixed line vs wireless
- commitments vs options
- pricing basis

Case: Pier 1 Imports

Business unit	Telecommunications service
3 zone offices distribution center	AT&T frame relay + ISDN back-up
32 regional offices	AT&T frame relay with no back-up
730 retail stores	Sprint frame relay

Business Factors

- business nature
- organization
- IT architecture
- planning horizon

Business Nature

- service
  - information
  - transaction
- data flows
  - symmetric
  - asymmetric

Case Study: Distance Education

- downlink from provider to student
  - multimedia
  - not interactive
  - same for all students
- uplink from student to provider
  - interactive
  - must be individual

Organizational Parameters

- organization
  - acceptance of change
  - risk tolerance
- human resources
- finances

IT Architecture

- processing
- software
- databases

Planning Horizon

- business growth
  - volume of communications
- international expansion
  - volume of communications
  - geographical coverage
- maturity of technology

Case: India's Stock Exchanges

- Bombay Stock Exchange (BSE): telephone trading
  - long waiting lists for service
  - unreliable
  - high prices for long distance
- 1994: National Stock Exchange (NSE): screen-based trading
  - Insat-2D satellite connexion
  - 1997: NSE daily volume reached US$500 million, eclipsing BSE with $300 million
- Oct. 1997: Insat-2D failed