10. Network planning and dimensioning

Literature

1. A. Olsson, ed. (1997)
   - “Understanding Telecommunications 1”
   - Studentlitteratur, Lund, Sweden

2. A. Girard (1990)
   - “Routing and Dimensioning in Circuit-Switched Networks”
   - Addison-Wesley, Reading, MA
• A simple model of a telecommunication network consists of
  – nodes
    • terminals
    • network nodes
  – links between nodes
• Access network
  – connects the terminals to the network nodes
• Trunk network
  – connects the network nodes to each other
Why network planning and dimensioning?

• “The purpose of dimensioning of a telecommunications network is to ensure that the expected needs will be met in an economical way both for subscribers and operators.”

Source: [1]
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Network planning in a stable environment (1)

• Traditional planning situation:

Business planning

Long and medium term network planning

Short term network planning

Operation and maintenance

Source: [1]

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Network planning in a stable environment (2)

• Traffic aspects
  – Data collection (current status)
    • traffic measurements
    • subscriber amounts and distribution
  – Forecasting
    • service scenarios
    • traffic volumes and profiles

• Economical aspects
• Technical aspects
• Network optimisation and dimensioning
  – hierarchical structure and topology
  – traffic routing and dimensioning
  – circuit routing
Traditional planning process by Girard (1)

- As with any decision process, network planning relies on **external information**
  - Forecast of demand for services over some planning horizon
  - Economic information concerning the cost structure of the network elements and maintenance
  - Knowledge about the technical capabilities of the available systems

- The planning problem can now be stated as follows:
  - to implement the first four layers of the OSI model
  - to provide the required physical support

Source: [2]

Traditional planning process by Girard (2)

- Assuming that all the protocol issues have been settled and the transmission technology is known, what remains is a complex, distributed and dynamic capacity-augmentation problem
  - only feasible solution approach: decomposition and iteration

- Stages of the planning process:
  - Topological design
  - Network-synthesis problem
    - Traffic routing
    - Dimensioning
  - Network-realization (circuit-routing) problem

- These four stages are interrelated
  ⇒ the planning process is **iterative** (at many levels)

- Different **planning horizons** at various stages

Source: [2]
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Planning process for dimensioning circuit switched networks by Girard

Traditional planning process by Girard (3)

- Topological design:
  - Determine where to place components and how to interconnect them
  - By methods of **topological optimization** and **graph theory**
  - Input:
    - information about transmission network summarized into a fixed interconnection cost per unit length between offices
    - switch costs depending just on the switching technology
  - Output:
    - connectivity matrix
    - optimal location of switches or concentrators (optionally)

Source: [2]
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Traditional planning process by Girard (4)

- Network synthesis:
  - Calculate the optimal size of the components (that is: the transmission and switching systems) within the topology specified and subject to GoS constraints on network-performance measures
  - By methods of **nonlinear optimization**
  - Input:
    - topology, traffic matrices, GoS constraints, cost function (unit cost)
  - Output:
    - route plan
    - set of logical links between the nodes (that is: requirements for transmission facilities betw. switching points)
  - Comprises of two iterated substages:
    - Traffic routing
    - Dimensioning
  - Specific to telecommunications!

Source: [2]

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Traditional planning process by Girard (5)

- Traffic routing:
  - Determine how to connect calls as they arrive, given the topology and size of the components

- Dimensioning:
  - Determine the size of the components subject to GoS constraints and given the topology and a routing method

Source: [2]
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Traditional planning process by Girard (6)

- Network realization:
  - Determine how to implement the capacity requirement (for transmission and switching equipments) using the available components and taking further into account reliability (⇒ multipath routing)
  - By methods of **multicommodity flow optimization**
  - Input:
    - logical-circuit demand
    - fixed costs, module costs and reliability of available components
    - other reliability requirements
  - Output:
    - physical circuits plan
    - detailed information of actual transmission cost between nodes

Source: [2]

Network planning in a turbulent environment (1)

- Additional decision data are needed from the following areas:
  - The market, with regard to a specific business concept
    - due to competition!
    - operator’s future role (niche): dominance/co-operation
  - Customer demands:
    - new services: Internet & mobility (first of all)
    - new business opportunities
  - Technology:
    - new technology: ATM, xDSL, GSM, CDMA, WDM
  - Standards:
    - new standards issued continuously
  - Operations and network planning support:
    - new computer-aided means
  - Costs:
    - trends: equipment costs going down, staff costs going up

Source: [1]
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Network planning in a turbulent environment (2)

- Safeguards for the operator:
  - Change the network architecture so that it will be more open, with generic platforms, if possible
  - Build the network with a certain prognosticated overcapacity (redundancy) in generic parts where the marginal costs are low

- New planning situation (shift of focus to a strategic-tactical approach):

  Business planning; Strategic-tactical planning of network resources for **flexible use**

  Business-driven, dynamic network management for **optimal use** of network resources

Source: [1]
Need for traffic measurements and forecasts

• To properly dimension the network we need to estimate the traffic offered

• If the network is already operating,
  – the current traffic is most precisely estimated by making traffic measurements

• Otherwise, the estimation should be based on other information, e.g.
  – estimations on characteristic traffic generated by a subscriber
  – estimations on the number of subscribers

• Long time-span of network investments ⇒
  – it is not enough to estimate only the current traffic
  – forecasts of future traffic are also needed
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Traffic forecasting

- Information about future demands for telecommunications
  - an estimation of future tendency or direction
- Purpose
  - provide a basis for decisions on investments in network
- Forecast periods
  - time aspect important (reliability)
  - need for forecast periods of different lengths

Source: [1]
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## Forecasting methods

- **Trend methods**
  - linear extrapolation
  - nr of subscribers increased yearly by about 200 in the past 5 years
  \[ \Rightarrow 3 \times 200 = 600 \] new subscribers in the next 3-year period
  - not suitable if growth is exponential
- **Statistical demand analysis**
  - network operator seeks to map out those factors that underlie the earlier development
  - changes that can be expected during the forecasting period are then collated
- **Assessment methods**
  - analogy method: situations or objects with similar preconditions will develop similarly

Source: [1]

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## Traffic forecast

- **Traffic forecast defines**
  - the estimated traffic growth in the network over the planning period
- **Starting point**:
  - current traffic volume during busy hour (measured/estimated)
- **Other affecting factors**:
  - changes in the number of subscribers
  - change in traffic per subscriber (characteristic traffic)
- **Final result (that is, the forecast)**:
  - **traffic matrix** describing the traffic interest between exchanges (traffic areas)
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**Traffic matrix**

- The final result of the traffic forecast is given by a **traffic matrix**
- Traffic matrix \( T = (T(i,j)) \)
  - describes traffic interest between exchanges
  - \( N^2 \) elements (\( N = \) nr of exchanges)
  - element \( T(i,i) \) tells the estimated traffic within exchange \( i \)
  - element \( T(i,j) \) tells the estimated traffic from exchange \( i \) to exchange \( j \)
- **Problem:**
  - easily grows too big: 600 exchanges \( \Rightarrow 360,000 \) elements!
- **Solution:** hierarchical representation
  - higher level: traffic between traffic areas
  - lower level: traffic between exchanges within one traffic area

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**Example (1)**

- **Data:**
  - There are 1000 private subscribers and 10 companies with their own PBX’s in the area of a local exchange.
  - The characteristic traffic generated by a private subscriber and a company are estimated to be 0.025 erlang and 0.200 erlang, respectively.
- **Questions:**
  - What is the total traffic intensity \( a \) generated by all these subscribers?
  - What is the call arrival rate \( \lambda \) assumed that the mean holding time is 3 minutes?
- **Answers:**
  - \( a = 1000 \times 0.025 + 10 \times 0.200 = 25 + 2 = 27 \) erlangs
  - \( h = 3 \) min
  - \( \lambda = a/h = 27/3 \) calls/min = 9 calls/min
Example (2)

- **Data:**
  - In a 5-year forecasting period the number of new subscribers is estimated to grow linearly with rate 100 subscribers/year.
  - The characteristic traffic generated by a private subscriber is assumed to grow to value 0.040 erlang.
  - The total nr of companies with their own PBX is estimated to be 20 at the end of the forecasting period.

- **Question:**
  - What is the estimated total traffic intensity $a$ at the end of the forecasting period?

- **Answer:**
  - $a = (1000 + 5\times100) \times 0.040 + 20 \times 0.200 = 60 + 4 = 64$ erlangs

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Example (3)

- **Data:**
  - Assume that there are three similar local exchanges.
  - Assume further that one half of the traffic generated by a local exchange is local traffic and the other half is directed uniformly to the two other exchanges.

- **Question:**
  - Construct the traffic matrix $T$ describing the traffic interest between the exchanges at the end of the forecasting period.

- **Answer:**
  - $T(i,i) = 64/2 = 32$ erlangs
  - $T(i,j) = 64/4 = 16$ erlangs

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$$
Determine the minimum \textbf{system capacity} needed in order that the incoming \textbf{traffic} meet the specified \textbf{grade of service}.
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Traffic dimensioning (2)

- Observation:
  - Traffic is varying in time
- General rule:
  - Dimensioning should be based on peak traffic not on average traffic
- However,
  - Revenues are based on average traffic
- For dimensioning (of telephone networks),
  peak traffic is defined via the concept of busy hour:

**Busy hour** ≈ the continuous 1-hour period for which the traffic volume is greatest

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Telephone network model

- Simple model of a telephone network consists of
  - network nodes (exchanges)
  - links between nodes
- Traffic consists of **calls**
- Each call has two phases
  - first, the connection has to set up through the network (**call establishment** phase)
  - only after that, the information transfer is possible (**information transfer** phase)
Two kinds of traffic processes

- Traffic process in each network node
  - due to call establishments
  - during the call establishment phase
    - each call needs (and competes for) processing resources in each network node (switch) along its route
    - it typically takes some seconds (during which the call is processed in the switches, say, some milliseconds)
- Traffic process in each link
  - due to information transfer
  - during the information transfer phase
    - each call occupies one channel on each link along its route
    - information transfer lasts as long as one of the participants disconnects
      - ordinary telephone calls typically hold some minutes
- Note: totally different time scales of the two processes

Simplified traffic dimensioning in a telephone network

- Assume
  - fixed topology and routing
  - given traffic matrix
  - given GoS requirements
- Dimensioning of network nodes: Determine the required call handling capacity
  - max number of call establishments the node can handle in a time unit
- Dimensioning of links: Determine the required number of channels
  - max number of ongoing calls on the link
Traffic process during call establishment (1)

Traffic process during call establishment (2)

- Call (request) arrival process is modelled as
  - a Poisson process with intensity $\lambda$
- Further we assume that call processing times are
  - IID and exponentially distributed with mean $s$
    - typically $s$ is in the range of **milliseconds** (not minutes as $h$)
    - $s$ is more a **system parameter** than a traffic parameter
- Finally we assume that the call requests are processed by
  - a single processor with an infinite buffer
- The resulting traffic process model is
  - the **M/M/1 queueing model** with traffic load $\rho = \lambda s$
Traffic process during call establishment (3)

- Pure delay system ⇒

Grade of Service measure = Mean waiting time $E[W]$

- Formula for the mean waiting time $E[W]$ (assuming that $\rho < 1$):

$$E[W] = s \cdot \frac{\rho}{1-\rho}$$

- $\rho = \lambda s$
- **Note**: $E[W]$ grows to infinity as $\rho$ tends to 1

Dimensioning curve

- Grade of Service requirement: $E[W] \leq s$
  ⇒ Allowed load $\rho \leq 0.5 = 50\% \Rightarrow \lambda s \leq 0.5$
  ⇒ Required service rate $1/s \geq 2\lambda$
**Dimensioning rule**

- To get the required Grade of Service (the average time a customer waits before service should be less than the average service time) …

... Keep the traffic load less than 50%

- If you want a less stringent requirement, still remember the **safety margin** …

Don’t let the total traffic load approach to 100%

- Otherwise you’ll see an explosion!

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**Example (1)**

**Assumptions:**
- 3 local exchanges completely connected to each other
- Traffic matrix $T$ describing the busy hour traffic interest (in erlangs) given below
- Fixed (direct) routing: calls are routed along shortest paths.
- Mean holding time $h = 3$ min.

**Task:**
- Determine the call handling capacity needed in different network nodes according to the GoS requirement $\rho < 50\%$
Example (2)

- **Node 1:**
  - call requests from own area: 
    \[ \frac{T(1,1) + T(1,2) + T(1,3)}{h} = \frac{90}{3} = 30 \text{ calls/min} \]
  - call requests from area 2: 
    \[ T(2,1) = \frac{30}{3} = 10 \text{ calls/min} \]
  - call requests from area 3: 
    \[ T(3,1) = \frac{30}{3} = 10 \text{ calls/min} \]
  - total call request arrival rate: 
    \[ \lambda(1) = 30 + 10 + 10 = 50 \text{ calls/min} \]
  - required call handling capacity: 
    \[ \rho(1) = \frac{\lambda(1)}{\mu(1)} = 0.5 \Rightarrow \mu(1) = 2 \times \lambda(1) = 100 \text{ calls/min} \]

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Example (3)

- **Node 2:**
  - total call request arrival rate: 
    \[ \lambda(2) = \frac{T(2,1) + T(2,2) + T(2,3) + T(1,2) + T(3,2)}{h} = \frac{75 + 15 + 15}{3} = 35 \text{ calls/min} \]
  - required call handling capacity: 
    \[ \mu(2) = 2 \times \lambda(2) = 70 \text{ calls/min} \]

- **Node 3:**
  - total call request arrival rate: 
    \[ \lambda(3) = \frac{T(3,1) + T(3,2) + T(3,3) + T(1,3) + T(2,3)}{h} = \frac{75 + 15 + 15}{3} = 35 \text{ calls/min} \]
  - required call handling capacity: 
    \[ \mu(3) = 2 \times \lambda(3) = 70 \text{ calls/min} \]
Traffic process during information transfer (1)

Traffic process during information transfer (2)

- Call arrival process has already been modelled as
  - a Poisson process with intensity $\lambda$
- Further we assume that call holding times are
  - IID and generally distributed with mean $h$
    - typically $h$ is in the range of minutes (not milliseconds as s)
    - $h$ is more a traffic parameter than a system parameter
- The resulting traffic process model is
  - the M/G/n/n loss model with (offered) traffic intensity $a = \lambda h$
Traffic process during information transfer (3)

- Pure loss system ⇒

Grade of Service measure = Call blocking probability $B$

- Erlang’s blocking formula:

$$B = \text{Erl}(n, a) = \frac{a^n}{n!} \sum_{i=0}^{n} \frac{a^i}{i!}$$

- $a = \lambda h$
- $n! = n(n - 1)(n - 2) \ldots 1$

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Dimensioning curve

- Grade of Service requirement: $B \leq 1\%$
  ⇒ Required link capacity: $n = \min\{i = 1, 2, \ldots \mid \text{Erl}(i, a) \leq B\}$
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Example (1)

- **Assumptions:**
  - 3 local exchanges completely connected to each other with two-way links
  - Traffic matrix $T$ describing the busy hour traffic interest (in erlangs) given below
  - Fixed (direct) routing: calls are routed along shortest paths.
  - Mean holding time $h = 3$ min.

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- **Task:**
  - Dimension trunk network links according to the GoS requirement $B < 1\%$

Example (2)

- **Link 1-2** (betw. nodes 1 and 2):
  - total offered traffic: $a(1-2) = T(1,2) + T(2,1)$
    $= 15 + 30 = 45$ erlang
  - required capacity: $n(1-2) = \min\{i \mid \text{Erl}(i, 45) < 1\%\}$
    $\Rightarrow n(1-2) = 58$ channels

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- **Link 1-3**:
  - required capacity: $n(1-3) = \min\{i \mid \text{Erl}(i, 45) < 1\%\}$
    $\Rightarrow n(1-3) = 58$ channels

- **Link 2-3**:
  - required capacity: $n(2-3) = \min\{i \mid \text{Erl}(i, 30) < 1\%\}$
    $\Rightarrow n(2-3) = 42$ channels
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Table: $B = \text{Erl}(n,a)$

- **$B = 1\%$**
  - $n$: $a$:  
    - 35 channels: 24.64 erlang  
    - 36 channels: 25.51 erlang  
    - 37 channels: 26.38 erlang  
    - 38 channels: 27.26 erlang  
    - 39 channels: 28.13 erlang  
    - 40 channels: 29.01 erlang  
    - 41 channels: 29.89 erlang  
    - 42 channels: 30.78 erlang  
    - 43 channels: 31.66 erlang  
    - 44 channels: 32.55 erlang  
    - 45 channels: 33.44 erlang

- **$B = 1\%$**
  - $n$: $a$:  
    - 50 channels: 37.91 erlang  
    - 51 channels: 38.81 erlang  
    - 52 channels: 39.71 erlang  
    - 53 channels: 40.61 erlang  
    - 54 channels: 41.51 erlang  
    - 55 channels: 42.41 erlang  
    - 56 channels: 43.32 erlang  
    - 57 channels: 44.23 erlang  
    - 58 channels: 45.13 erlang  
    - 59 channels: 46.04 erlang  
    - 60 channels: 46.95 erlang

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End-to-end blocking probability

- Thus far we have concentrated on the single link case, when calculating the call blocking probability $B_c$.
- However, there can be many (trunk network) links along the route of a (long distance) call. In this case it is more interesting to calculate the total end-to-end blocking probability $B_e$ experienced by the call. A method (called Product Bound) to calculate $B_e$ is given below.
- Consider a call traversing through links $j = 1, 2, \ldots, J$. Denote by $B_c(j)$ the blocking probability experienced by the call in each single link $j$. Then

$$B_e = 1 - (1 - B_c(1))*(1 - B_c(2)) \ldots *(1 - B_c(J))$$

$B_c(j)$’s small $\Rightarrow B_e \approx B_c(1) + B_c(2) + \ldots + B_c(J)$
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Example

- The call from A to B is traversing through trunk network links 1 and 2
- Let $B_c(1)$ and $B_c(2)$ denote the call blocking probability in these links
- Product Bound (PB):
  \[ B_e = 1 - (1 - B_c(1))(1 - B_c(2)) = B_c(1) + B_c(2) - B_c(1)B_c(2) \]
- Approximately:
  \[ B_e \approx B_c(1) + B_c(2) \]