Tele-Traffic Analysis

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Introduction to Tele-Traffic Analysis

- **The basic goal of traffic analysis is to provide a method for determining the cost-effectiveness of various sizes and configurations of network.**
    - **Why?** The amount of common equipment designed into a network is determined under an assumption that not all users of the network need service at one time.
    - The exact amount of common equipment required is unpredictable because of the random nature of the arrival of service requests and usually require unpredictable service times.
- **Traffic** in a communications network refers to the aggregate of all user requests being serviced by the network.

Introduction to Tele-Traffic Analysis

- The **first** step of traffic analysis is the **characterization of traffic arrivals and service times** in a probabilistic framework.
  - **Then,** the effectiveness of a network can be evaluated in terms of *how much* **traffic it carries under normal or average loads** and *how often* **the traffic volume exceeds the capacity of the network**.
  - That is to determine the ability of a telecommunication network to carry a given traffic at a particular loss probability.
- The basic purpose is to determine the conditions under which adequate service is provided to subscribers while making economical use of the resources providing the service.

General Categories of Tele-Traffic Analysis

- The techniques of traffic analysis can be divided into two general categories: **loss systems** and **delay systems**.
  - The appropriate analysis category for a particular system depends on the system's treatment of overload traffic.
- In a **Loss System**, overload traffic is rejected without being serviced.
  - Conventional circuit switching operates as a loss system since excess traffic is blocked and not serviced without a retry on the part of the user.
  - In some instances "lost" calls actually represent a loss of revenue to the carriers by the virtue of their not being completed.

General Categories of Tele-Traffic Analysis

- In a **Delay System**, overload traffic is held in a queue until the facilities become available to service it.
  - Store-and-foeward message or packet switching obviously possesses the basic characteristics of a delay system.
  - Sometimes, however, a packet-switching operation can also contain certain aspect of a loss system. Limited queue sizes and virtual circuits both imply loss operations during traffic overloads.
  - Circuit-switching networks also incorporate certain operations of a delay nature in addition to the loss operation of the circuits themselves. For example, access to a digit receiver, an operator, or a call processor is normally controlled by a queuing process.

General Categories of Tele-Traffic Analysis

- The basic measure of performance for a loss system is the probability of rejection **(blocking probability)**.
    - A delay system, on the other hand, is measured in terms of **service delays**.

Traffic Characterization

- In the domain of traffic flow analysis, the blocking probability analyses are referred to as **congestion theory** and delay analyses are referred to as **queuing theory**.
  - In a circuit-switched network, the *flow* of messages is not so much of the concern as are the *holding times* of the common equipment. From a network point of view, it is holding of these resources that is important, not the flow of information within individual circuits.
  - On the other hand, message-switching and packet-switching networks are directly concerned with the actual flow of information, since in these systems traffic on the transmission links is directly related to the *activity of the sources*.

Traffic Characterization

- The unpredictable nature of communications traffic arises as a result of *two* underlying random processes: **call arrivals** and **holding times**.
  - An arrival from any particular user is generally assumed to occur purely by chance and be totally independent of arrivals from other users. Thus, the number of arrivals during any particular time interval is *indeterminate*. In most cases, holding times are also distributed randomly.
  - Traffic load presented to a network is fundamentally dependent on both the **frequency of arrivals** and the **average holding time** for each arrival.

Traffic Measurement

- One measure of network capacity is the volume of traffic carried over a period of time.
  - Traffic volume is essentially *sum of all holding times* carried during the interval.
  - A more useful measure of traffic is the **traffic intensity** (also called traffic flow).
    - **Traffic intensity** is obtained by dividing the traffic volume by the length of time during which it is measured.
    - Thus **traffic intensity** represents the *average activity* during a period of time.
    - Although traffic intensity is fundamentally dimensionless (time divided by time), it is usually expressed in units of **erlangs**.

Traffic Statistics

- The incoming traffic undergoes variations in many ways due to peak hours, business hours, seasons, weekends, festival, location of exchange, tourism area etc., the traffic is unpredictable and random in nature. So, the traffic pattern/characteristics of an exchange should be analysed for the system design.
- **Calling rate (λ) or Average Arrival Rate**
    - This is the *average number of requests* for connection that are made per unit of time. If n is the average number of calls to and from a terminal during a period T seconds, the calling rate is defined as,

$$\lambda = \frac{n}{T} \tag{1}$$

- The average calling rate is measured in *calls per hour*.

Traffic Statistics

- **Holding time or Service Time**
  - The average holding time or service time (h) is the *average duration* of occupancy of a traffic path by a call.
    - For voice traffic, it is the average holding time per call in *hours* or *100 seconds* or *seconds per call* or *minutes per call.*
    - For data traffic, average transmission per message in seconds.
  - The reciprocal of the average holding time is referred to as service rate (μ) in *calls per hour* is given as,

$$\mu = \frac{1}{h} \tag{2}$$

Traffic Statistics

- **Average Occupancy or Traffic Intensity**
  - If the average number of calls to and from a terminal during a period T seconds is n and the average holding time is h seconds, the average occupancy of the terminal is given by,

$$A = \frac{n}{T}h = \lambda h = \frac{\lambda}{\mu} \tag{3}$$

  - Thus, average occupancy is the ratio of **average arrival rate** to the **average service rate**.
  - It is the ratio of the period for which the server is occupied to the total period of observation, and is measured in **Erlangs**.
  - Average occupancy is also referred as **traffic flow** or **traffic intensity** or **carried traffic**.

Traffic Statistics

- **Average Occupancy or Traffic Intensity**
  - Notice that traffic intensity is only a measure of average utilization during a time period and does not reflect the relationship between arrivals and holding times.
  - Many short calls can produce the same traffic as few long ones.
  - In many of the analyses that follow the results are dependent only on the traffic intensity. In some cases, however, the results are also dependent on the individual arrival patterns and holding time distributions.
  - Traffic engineering depends not only on overall traffic volume but also on time-volume traffic patterns within the network.

Traffic Statistics

- **Erlang**
  - A server is said to have 1 erlang of traffic if it is occupied for the entire period of observation (usually 60 minutes). More simply, 1 erlang represents 1 circuit occupied for 1 hour.
  - The maximum capacity of a single server (or channel) is 1 erlang (server is always busy).
  - Traffic intensity is measured in two ways. They are (a) **Erlangs** and (b) **Century Call Seconds (CCS)**
  - The international unit of traffic is the **Erlang**. The relationship between erlangs and CCS units can be derived by observing that there are 3600 seconds in an hour. (1 erlang = 36 CCS)

Traffic Statistics

- **Busy Hour**
  - It is defined as the 60 minutes interval in a day, in which the traffic is the highest or continuous 60 minutes interval for which the traffic volume or the number of call attempts is greatest.
  - The *busy hour* vary from exchange to exchange, month to month and day to day and even season to season.
- **Time Consistent Busy Hour**
  - The 1 hour period starting at the *same time each day* for which the average traffic volume or the number of call attempts is greatest over the days under consideration.

Traffic Statistics

- **Busy Hour Call Attempts (BHCA)**
  - It is defined as the number of call attempts in a busy hour.
  - It is exchange load in busy hour, and it may not go beyond 70-80% of its designed value.
  - It is an important parameter in deciding the processing capacity of an exchange.
  - EWSD switch CP-113C can support 6 million call attempts in the busy hour.

Traffic Statistics

- **Busy Hour Calling Rate (BHCR)**
  - It is defined as the average number of calls originated by a subscriber during the busy hour.
  - It is a useful parameter in designing a local office to handle the peak hour traffic.

$$\texttt{BHCR} = \frac{\texttt{Average Busy Hour Calls}}{\texttt{Total Number of Subscribers}} \quad (4)$$

$$= \frac{\texttt{BHCA} \times \texttt{CCR}}{\texttt{N}} \quad (5)$$

  - If the number of calls during the busy hour be 6000 in a city exchange serving 5000 subscribers, then the calling rate is $\frac{6000}{5000} = 1.2$

Traffic Statistics

- **Call Completion Rate**
  - It is defined as the ratio of successfully completed calls to the total number of attempted calls (ITU-T E600/2.13) or the ratio of the number of completed call attempts to the total number of call attempts, at a given point of a network.
  - A *complete call* is a call that is released by normal call clearing (i.e., *Released Message* and *Released Complete Message* have been successfully exchanged in the SS7 signaling flow), be it during a ringing phase or conversation phase by either the caller or called party. A CCR value of 0.75 is considered excellent and 0.70 (70%) is usually expected.

$$\mathtt{CCR} = \frac{\mathtt{Number\ of\ calls\ completed}}{\mathtt{Number\ of\ calls\ attempted}} \times 100 \qquad (6)$$

Traffic Statistics

- **Answer to Seizure Ratio (ASR)**
  - It is defined as the ratio of the number of seizures that result in an answer signal to the total number of seizures (ITU-T E600/2.14) or ASR is line seizures that are answered by person or device divided by total number of seizures. Note that the *seizure* is achieved after a successful *call setup*. It means seizing a trunk circuit for conversation or other network services.
  - Normally, desirable ASR values start from 40%.

$$\texttt{ASR} = \frac{\texttt{Number of answered calls}}{\texttt{Number of seized calls}} \times 100 \qquad (7)$$

  - Low ASR values may be due to busy destination lines or far-end switch congestion.

Traffic Statistics

- **Network Effectiveness Ratio (NER)**
  - It measures the ability of a network to deliver a call to the called terminal.
  - It describes network performance and is designed to exclude user behavior.
  - `NER` is the sum of *answered calls + user busy + ring no answer + terminal reject* to the *total number of call attempts (seizures)*.
- **Call Setup Success Rate (CSSR)**
  - It is the fraction of the attempts to make a call that result in a connection to the dialled number (due to various reasons not all call attempts end with a connection to the dialled number).

Traffic Statistics

- **Call Failure Rate (CFR)**
  - It is defined as the ratio of the number of failed calls to the number of seized calls.

$$\texttt{CFR} = \frac{\texttt{Number of calls failed}}{\texttt{Number of seized calls}} \times 100 \tag{8}$$

- **Call Drop Rate (CDR)**
  - It is defined as the ratio of abnormal disconnect of calls to total calls established.
  - The dropped-call rate in conventional (land-line) networks is extremely low and is significantly less than 0.01%.

Traffic Statistics

- **Mean Holding Time (MHT)**
  - This is the average time duration for which a circuit is busy in a specified period.
  - *call setup time + conversation time + call release time*
- **Mean Conversation Time (MCT)**
  - This is the average time of conversation on calls during specified period.

Traffic Statistics

- **Trunk Efficiency**
  - It is the efficiency of a circuit/trunk to handle the traffic.
    - 0.8 Erlang/Ckt as per PTCL standard.
    - Trunk is the dedicated circuit required to carry calls from one exchange to another exchange.

Traffic Statistics

- **Grade of Service (GoS)**
  - The grade of service refers to the proportion of unsuccessful calls relative to the total number of calls. GoS is defined as the ratio of lost traffic to offered traffic.

$$\texttt{GoS} = \frac{\texttt{Blocked Busy Hour Calls}}{\texttt{Offered Busy Hour Calls}} \tag{9}$$

$$\texttt{GoS} = \frac{\texttt{Lost Traffic}}{\texttt{Offered Traffic}} = \frac{A - A_o}{A} \tag{10}$$

  - A_o = carried traffic (call success), A = offered traffic (call attempts), $A - A_o$ = lost traffic (call failure)
  - GoS depends on *traffic intensity* and *number of trunks* available.

Traffic Statistics

- **Grade of Service (GoS)**
  - The smaller the value of grade of service, the better is the service. The recommended GoS is 0.002, *i.e.* 2 call per 1000 offered may lost. In a system, with equal no. of servers and subscribers, GoS is equal to zero.
  - The overall GoS is in fact approximately the sum of the component GoS. Usually a switching centre is broken into following components.
    - an internal call (subscriber to switching office)
    - an outgoing call to the trunk network (switching office to trunk)
    - the trunk network (trunk to trunk)
    - a terminating call (switching office to subscriber)

Traffic Statistics

- **Reasons of Call Failures**
  - Due to customer behaviour
    - Wrong number dialed
    - No answer
    - Busy subscriber
    - Long delay
  - Due to system
    - Technical irregularities (Internal and External)

Traffic Statistics

- **Grade of Service (GoS)**
  - **Example:** During a busy hour, 1400 calls were offered to a group of trunks and 14 calls were lost. The average call duration has 3 minutes. *Find (a) Traffic offered (b) Traffic carried (c) GoS (d) The total duration of period of congestion.*

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  - **Example:** During a busy hour, 1400 calls were offered to a group of trunks and 14 calls were lost. The average call duration has 3 minutes. *Find (a) Traffic offered (b) Traffic carried (c) GoS (d) The total duration of period of congestion.*

    Answer: $n = 1400$, $h = 3$, $T = 60$, lost calls $= 14$

    (a) Traffic offered $= A = \frac{1400 \times 3}{60} = 70E$

    (b) Traffic carried $= A_o = \frac{1386 \times 3}{60} = 69.3E$

    (c) GoS $= \frac{A - A_o}{A} = \frac{0.7}{69.3} = 0.01$

    (d) Period of congestion $= 0.01 \times 3600 = 36$ seconds

Blocking Probability and Congestion

- **Blocking Probability vs GoS**
  - GoS is a measure from subscriber point of view
    - GoS is calculated based on the number of rejected calls
  - Blocking probability is a measure from the network or switching point of view
    - Blocking probability is calculated by observing the busy servers in the switching system
    - Blocking probabilities can be evaluated using various techniques such as Lee graphs and Jacobaeus methods

Blocking Probability and Congestion

- **Congestion theory** deals with the probability that the offered traffic load exceeds some value.
  - During congestion, no new calls can be accepted.
  - There are two ways of specifying congestion. They are *time congestion* and *call congestion*.
    - Time congestion is the percentage of time that all servers in a group are busy.
    - The call or demand congestion is the proportion of calls arising that do not find a free server or it is the probability that the calls cannot be connected due to the lack of resources through the switching network.

$$\texttt{Call Congestion} = \frac{\texttt{Number of calls rejected}}{\texttt{Number of calls offered}}$$

Blocking Probability and Congestion

- In general GoS is called *call congestion* or *loss probability* and the blocking probability is called *time congestion*.
- If the number of sources is equal to the number of servers, the *time congestion* is finite, but the *call congestion* is zero.
- When the number of sources is large, the probability of a new call arising is independent of the number already in progress and therefore the *call congestion* is equal to *time congestion*.

Types of Traffic

- **Originating Traffic:** Traffic generated by subscriber connected to the exchange.
- **Originating Outgoing Traffic:** Originating traffic destined for other exchanges.
- **Internal Traffic:** Part of the originating traffic destined for subscribers connected to the exchange.
- **Terminating Traffic:** Traffic received by subscribers connected to the exchange.
- **Incoming External Traffic:** Traffic received on trunks from other exchanges.
- **Outgoing External Traffic:** Traffic destined for other exchanges.
- **Transit Traffic:** Part of incoming external traffic destined to other exchange.

Traffic Measurement Examples

- **Example:** A trunk / circuit is engaged on different calls for a total time of 25 minutes per hour. Calculate the traffic intensity on average.

Traffic Measurement Examples

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  Answer: $\texttt{Traffic Intensity} = \frac{25}{60} = 0.41\text{E}$

Traffic Measurement Examples

- **Example:** One hour measurement on 4 trunks/ circuits on a route show that these are engaged for 25, 15, 18 and 12 minutes respectively. Calculate the traffic intensity on average.

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  Answer: $\texttt{Traffic Intensity} = \frac{25+15+18+12}{60} = 1.2\text{E}$

Traffic Measurement Examples

- **Example:** In a local exchange, total number of calls during one hour are 1800. The average holding time is 3 minutes. Calculate the traffic intensity on average.

Traffic Measurement Examples

- **Example:** In a local exchange, total number of calls during one hour are 1800. The average holding time is 3 minutes. Calculate the traffic intensity on average.

  Answer: $A = \frac{n}{T}h = \frac{1800}{60} \times 3 = 90\text{E}$

Traffic Measurement Examples

- **Example:** On average, during the busy hour, a company makes 120 outgoing calls of 2 minutes average duration and receives 200 incoming calls of 3 minutes average duration. Find the outgoing traffic, incoming traffic, and the total traffic.

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  Answer:

  (i) The outgoing traffic in erlang is $\frac{120 \times 2}{60} = 4\text{E}$

  (ii) The incoming traffic in erlang is $\frac{200 \times 3}{60} = 10\text{E}$

  (iii) The total traffic is $4 + 10 = 14\text{E}$

Traffic Measurement Examples

- **Example:** During the busy hour, on average a customer with a single telephone line makes 3 calls and receives 3 calls with the average call duration of 2 minutes. What is the probability that a caller will find the line engaged?

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  Answer: The probability of line being engaged or occupancy of line in erlang $= \frac{(3+3)\times 2}{60} = 0.2\text{E}$

Traffic Measurement Examples

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  Answer:

  $\mathtt{N} = 2000$ subscribers, $\mathtt{BHCA} = 10000$, $\mathtt{CCR} = 60\%$

$$\begin{aligned}\mathtt{BHCR} &= \frac{\mathtt{Average\ Busy\ Hour\ Calls}}{\mathtt{Total\ Number\ of\ Subscribers}} \\ &= \frac{\mathtt{BHCA} \times \mathtt{CCR}}{\mathtt{N}} \\ &= \frac{10000 \times 0.6}{2000} = 3\end{aligned}$$

Traffic Measurement Examples

- **Example:** In a group of 10 servers, each is occupied for 30 minutes in an observation interval of two hours. Calculate the traffic carried by the group.

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  Answer:

  Number of servers = 10
  Average occupancy or Traffic carried (A) = ?

  - Traffic carried per source = $\frac{30\text{minutes}}{120\text{minutes}} = 0.25\text{E}$
  - Traffic carried by the group = $10 \times 0.25\text{E} = 2.5\text{E}$

Traffic Measurement Examples

- **Example:** A group of 20 servers carry a traffic of 10 Erlangs. If average duration of a call is 3 minutes, calculate the number of calls put through by a single server and a group as a whole in one hour period.

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  Answer:

  Number of servers = 20, Average occupancy (A) = 10 Erlangs, Average call duration = 3 minutes

  - Traffic per server $= \frac{10}{20} = 0.5$ E i.e. a server is busy for 30 minutes or half an hour.
  - Number of call put through by one server $= \frac{\texttt{Server busy time}}{\texttt{Call duration}} = \frac{30}{3} = 10$ calls
  - Total number of calls put through by group = 10 calls × 20 servers = 200 calls

Traffic Measurement Examples

- **Example:** A subscriber makes three calls of duration three, four and two minutes in one hour period. Calculate the subscriber traffic in Erlangs, CCS, and CM.

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  Answer:

  - Subscriber traffic in Erlangs $= \frac{\texttt{Busy period}}{\texttt{Total period}}$

    Subscriber traffic in Erlangs $= \frac{(3+4+2)}{60} = 0.15$ E
  - Traffic in CCS$= 0.15 \times 36 = 5.4$ CCS
  - Traffic in CM $= 0.15 \times 60 = 9$ CM

Traffic Measurement Examples

- **Example:** Consider a group of 1200 subscribers which generate 600 calls during the busy hour. The average holding time is 2.2 minutes. What is the offered traffic in erlangs, CCS and CM.

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  Answer: n = 600, h = 2.2 minutes, T = 60 minutes

  - Traffic intensity in Erlangs $= \frac{n}{T}h = \frac{600}{60}2.2 = 22$ E
  - Traffic in CCS$= 22 \times 36 = 792$ CCS
  - Traffic in CM $= 22 \times 60 = 1320$ CM

Traffic Measurement Examples

- **Example:** Over a 20 minute observation interval, 40 subscriber initiate calls. Total duration of the calls is 4800 seconds. Calculate the load offered to the network by the subscriber and the average subscriber traffic.

Traffic Measurement Examples

- **Example:** Over a 20 minute observation interval, 40 subscriber initiate calls. Total duration of the calls is 4800 seconds. Calculate the load offered to the network by the subscriber and the average subscriber traffic.

  Answer: Number of subscribers = 40

  - Average arrival rate $= \frac{\texttt{Number of subscribers}}{\texttt{Observation interval}}$

    Average arrival rate $= \frac{40}{20} = 2$ calls/minute
  - Average holding time $= \frac{\texttt{Total duration of calls}}{\texttt{Number of subscribers}}$

    Average holding time $= \frac{4800/60}{40} = 2$ minutes/call
  - Offered traffic = Average arrival rate × Average holding time $= 2 \times 2 = 4$ E
  - Average subscriber traffic $= \frac{\texttt{Offered traffic}}{\texttt{Number of subscribers}}$

    Average subscriber traffic $= \frac{4}{40} = 0.1$ E

Traffic Measurement Examples

- **Example:** A group of trunks are offered 120 calls during busy hour with a duration of 4 minutes. One of the call fails to find a disengaged (free) trunk. Find the traffic offered to the group and the traffic carried by the group.

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  Answer: Number of call attempts = 120, Average holding time = 4 minutes

  - Average arrival rate $= \frac{\texttt{Number of call attempts}}{\texttt{Observation interval}}$
    Average arrival rate $= \frac{120}{60} = 2$ calls/minute
  - Offered traffic = Average arrival rate × Average holding time $= 4 \times 2 = 8$ E
  - Number of carried calls $= 120 - 1 = 119$ calls
  - Carried traffic $= 4 \times \frac{119}{60} = 7.93$ E

Traffic Measurement Examples

- **Example:** If a group of 20 trunk carries 10 erlangs and the average call duration is 3 minutes. Calculate average number of calls in progress and total number of calls originating per hour.

Traffic Measurement Examples

- **Example:** If a group of 20 trunk carries 10 erlangs and the average call duration is 3 minutes. Calculate average number of calls in progress and total number of calls originating per hour.

  Answer: Number of trunks = 20, Traffic intensity = 10E, Holding time = 3 minutes

  - Traffic intensity per trunk = $\frac{10E}{20}$ = 0.5 E/trunk
    Average number of call in progress per trunk for 1 erlang of traffic for 60 minutes = 20
    For 0.5 erlangs, average number of calls in progress will be = $\frac{20}{1}0.5 = 10$
  - Traffic intensity (A) = $\frac{n}{T}h$
    $10E = \frac{n}{60}3 \Rightarrow n = \frac{10\times60}{3}$ = 200 calls

Questions

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