Mobile Communication Systems

Part V- Traffic Engineering

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Contents

- Problems + design considerations
- Grade of services (GOS)
- Traffic intensity
- Efficiency measure

Traffic Engineering

It

- is a method of optimizing the performance of a telecommunication network by dynamically analyzing, predicting, and regulating the behaviour of data transmitted over that network.
- uses statistical techniques such as queuing theory to predict and engineer the behaviour of telecommunications networks such as telephone networks or the Internet.
- depends on the type of traffic (both homogenous and heterogeneous) in the network
  - Homogeneous type:
    - *Describe the classical telecommunication services based on voice transmission and switching*
  - Heterogeneous type:
    - *Includes integrated traffic streams from different sources (voice, audio, video, data) into a single network*

Traffic Theory ……

- Covers specific types of random processes in telecommunications
  - Average connection duration
  - Average number of users
  - Busy time
  - Service time
  - Call arrival

Traffic Engineering

- Required in telecommunications network planning to ensure that costs are minimised without compromising the **quality of service** (QoS) delivered to the users.
  - It is based on probability theory and can be used to analyse mobile radio networks and other telecommunications networks.
- Mobile radio networks have traffic issues, which do not arise in the fixed line PSTN. A mobile handset, moving in a cell, receives a signal with varying strength, which is subjected to:
  - slow fading
  - fast fading
  - interference from other signals.

  Thus resulting in degradation of the carrier-to-interference (*C*/*I*) ratio.
    - A high *C*/*I* ratio results in quality communication.
- A good *C*/*I* ratio is achieved by using optimum power levels through the power control of most links.
  - When carrier power is too high, excessive interference is created, degrading the *C*/*I* ratio for other traffic and reducing the traffic capacity of the radio subsystem.
  - When carrier power is too low, *C*/*I* is too low and QoS targets are not met.

Traffic Engineering ….

- It balances the following factors based on the given amount of traffic:
    - **Grade of Service (GOS)**
    - **Resources (e.g., trunk channels)**
- Two types of systems are implemented to provide voice communications
    - **Blocking**
        - **Voice or data is blocked (by a busy signal) if network resource (e.g., trunk channel) is not available.**
        - **GoS = Blocking probability**
    - **Delay system**
        - **Voice or data is queued until network resource is available**
        - **GoS = Queueing probability and the average time in the queue**

Traffic Engineering – Terminologies

- **Arrival Rater**
  - the number of calls arriving during a finite time period.
  - Call arrivals are independent of each other
- **Poisson Arrival Process -** the most common assumption used in traffic engineering for the distribution of call arrivals. Calls are made randomly and independent of each others.
- **Blocking -**
  - Occurs whenever the number of calls (in or out) exceeds the number of lines.
  - Blocking probability is expressed as a percentage of denial, e.g., for 1 call in 100 blocked is expressed as 0.01 (1% of the offered calls is expect to be blocked).
- **Queuing -** waiting of calls until resources becomes available.

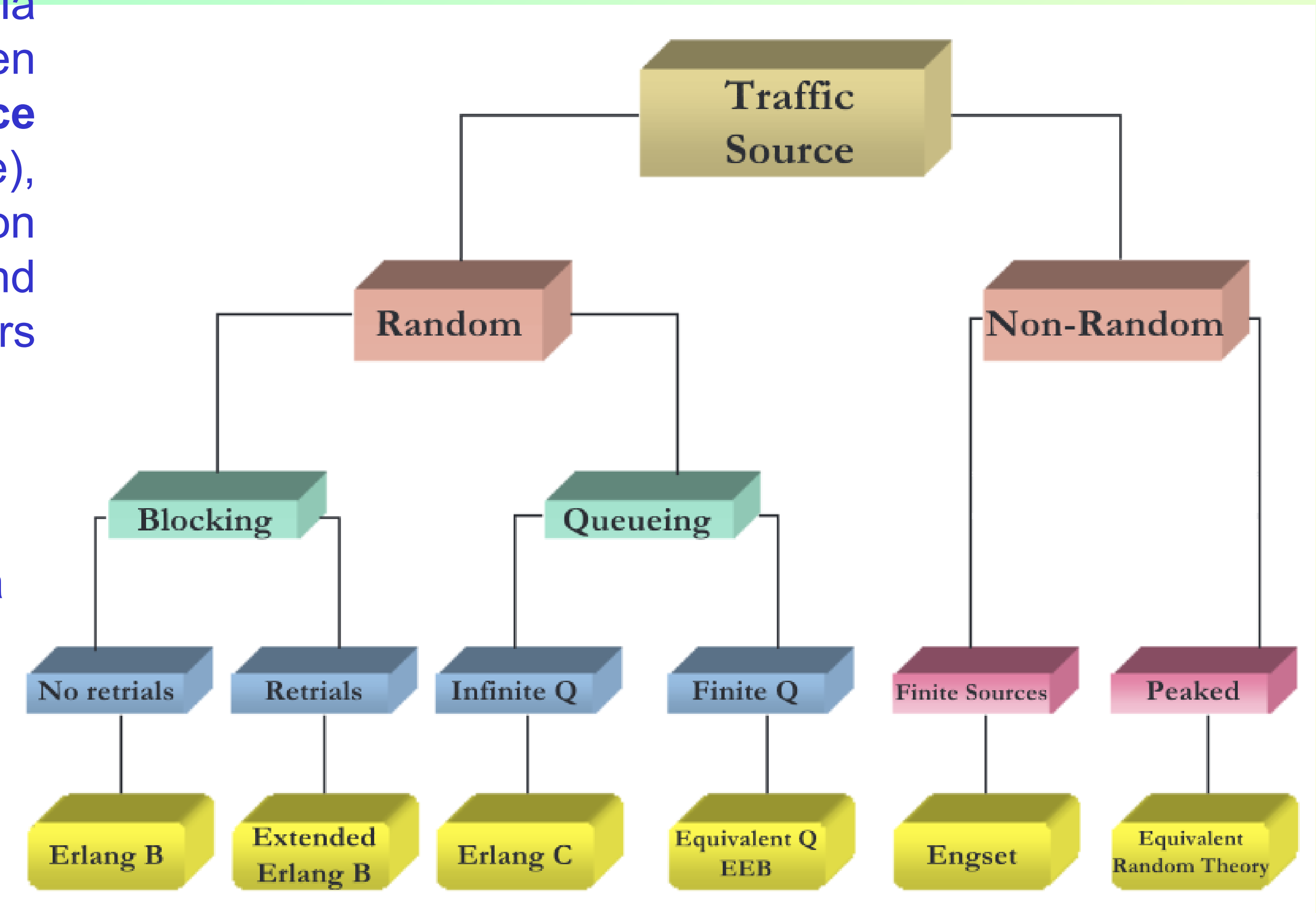
Traffic Engineering – Terminologies

- **Holding Time -** the mean length of time that a resource is being held (e.g., the duration of a phone call)
- **Traffic volume -** for an interval is the sum of all the traffic holding times for that interval
- **Traffic intensity =** traffic volume / time interval, which is a measure of demand
- **Erlang -** describe traffic intensity in terms of the number of hours of resource time required per hour of elapsed time. It dependents on the observation time;
  - e.g., if the observation time is 10 minutes, and the facility is in use for the full time, then that is equal to 1 Erlang
- **CCS (Centum Call Seconds) -** measures the exact same traffic intensity as Erlangs, but expresses it as the number of 100 second holding times required per hour. E.g.,

10 mins of traffic = 600 seconds
= 600 sec./100
= 6 CCS

Traffic Engineering – Decision Tree

The factors dictating the formula that best applies to a given situation include **source population** (finite or infinite), **holding time** distribution (constant or exponential), and **call disposition** when all servers are busy (blocked or queued).



Three most widely uses formula types:

- **Blocking formulas that assume infinite sources**
- **Blocking formulas that assume finite sources**
- **delay formulas**

Traffic Measurement Unites

- **Erlangs:** Traffic intensity (named after a Danish mathematician) is the average number of calls simultaneously in progress over a certain time. It is a dimensionless unit.

  one hour of continuous use of one channel = 1 Erlang

  - **1 Erlang = 1 hour (60 minutes) of traffic**

  – In data communications, an 1 E = 64 kbps of data

  – In telephone, 1 Erlang = 60 mins = 1 x 3600 call

- **% of Occupancy**

A.K. Erlang, 1878-1929

Erlangs - Example

- For example, if a group of users made 30 calls in one hour and each call had an average call duration of 5 minutes, then the number of Erlangs this represents is worked out as follows:

Minutes of traffic in the hour = number of calls x duration

Minutes of traffic in the hour = 30 x 5

Minutes of traffic in the hour = 150

Hours of traffic in the hour = 150 / 60

Hours of traffic in the hour = 2.5

Traffic figure = 2.5 Erlangs

Traffic Capacity

Depends on:

- Quality of services provided by different service providers
- Traffic congestion and blocking
- Probability of waiting before a call is connected
- Dominant coverage area
- C/I
- Dropped call rate
- Handover failure rate
- Overall call success rate ...

All these can be explained by QoS!

GoS

- Used for assessing performance, reliability and usability of telecommunications services.
- Is a measure of the call blocking in **voice traffic**, where resources allocation is **deterministic.**

or

- The ability to make call during the busiest time
- Is typically given as the likelihood that a call is blocked or the likelihood of a call experiencing a delay greater than a certain queuing time.
- Is determined by the available number of channels and used to estimate the total number of users that a network can support.

For example, if GoS = 0.05, one call in 20 will be blocked during the busiest hour because of insufficient capacity

Cellular GoS

- In general, GoS is measured by considering traffic carried and traffic offered, and then calculating the traffic blocked and lost.

  The proportion of lost calls is the measure of GoS.

  GoS = Number of lost calls / Number of offered calls

- For cellular circuit groups, $GoS_{acceptable}$ = 0.02. I.e., at busy period, 2 users out of 100 will encounter a call refusal.
- GoS is calculated using **Erlang-B formula**, as a function of the number of channels required for the offered traffic intensity.
- **There is a trade-off between the QoS and channel utilization.**

Traffic Voulume

Is a measure of the total work done by a resource or facility, normally over 24 hours, which is given by:

$$V = \alpha . H$$

α: Calls in time period T
H: Mean holding time

Traffic Intensity

Is a measure of the average occupancy of a resource during a specified period, normally a busy hour. It is generated by a single user, which is defined as:

$$A = V/T = \mu . H \qquad \text{Erlangs}$$

μ - Calling rate (i.e., average number of calls requested/hour)

A is generated according to Poisson model with inter-arrival time λ (negative exponential)

$$A = \lambda / \mu \qquad \text{Erlangs}$$

If there are *U* users and an unspecified number of channels, then: **the total offered traffic intensity**:

$$A_T = UA \qquad \text{Erlangs}$$

Busy hours traffic: Calls/busy hours *Mean call hold time

Traffic Intensity - *contd.*

In a trunks system of *C* channels and equally distributed traffic among the channels, **the traffic intensity per channel** is:

$$A_c = UA / C$$ Erlangs/channels

The traffic volume $V = A * T$ Erlangs-Hours

Example I

A call was established at 1 am between mobile and MSC. Assuming a continuous connection and data transfer rate at 30 kbit/s, determine the traffic intensity if the call is terminated at 1.50 am.

Solution:

Traffic intensity A = (1 call)*(50 mins)*(1 hour/60 min) = 0.833 Er

Note, that A has nothing to do with the data rate, only the holding time is taken into account.

Note:

- *If A > 1 Erlang: The incoming call rate exceeds the outgoing calls, thus resulting in queuing delay which will grow without bound (if A stays the same).*
- *If A is < 1 Erlang, then the network can handle more average traffic*.

Example II

- Consider a PSTN which receives 240 calls/hr. Each call lasts an average of 5 minutes. What is the outgoing traffic intensity to the public network.

Solution

$A = \mu * H$

μ = 240 calls/hr and H = 5 minutes

A = (240 calls /hr) x (5 min/call) = 1200 min/hr

Erlang cannot have any unit so

A= 1200 min/hr * (1 hour/60 minutes) = 20 Erlangs

So 20 hours of circuit talk time is required for every hour of elapsed time. An average of T1 voice circuits busy at any time is 20. (Or 20 hours of continuous use of 20 channels.)

Traffic Intensity – contd.

- QoS is expressed in terms of blocking probability:

$$P_B = (A \cdot C)$$

Where *B* = Erlang – B Formula; *A* = Traffic intensity; *C* = No of channels (lines)

Offered traffic A_{of}: Volume of traffic i.e., all attempted calls(blocked or not) defined as:

Offered traffic = carried traffic + overflow (lost traffic)

Carried traffic A_{ca}: The actual traffic carried.

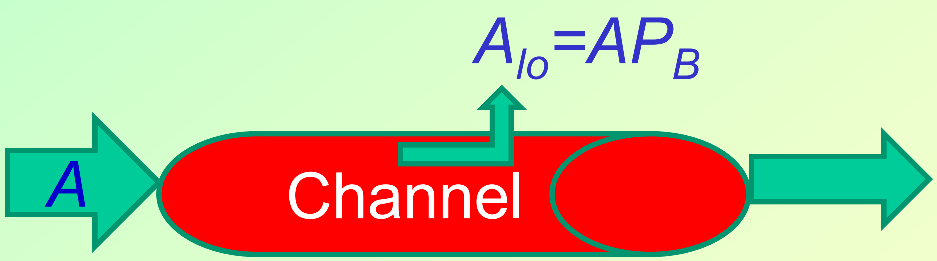
Overflow traffic A_{lo}: Portion of the traffic not processed.

Traffic Intensity – contd.

Offered traffic: Volume of traffic i.e., all attempted calls(blocked or not) defined as:

Traffic intensity = **Offered traffic = carried traffic + overflow (lost traffic)**

$$\mathbf{A = A_{of} = A_{of} + A_{l}}$$



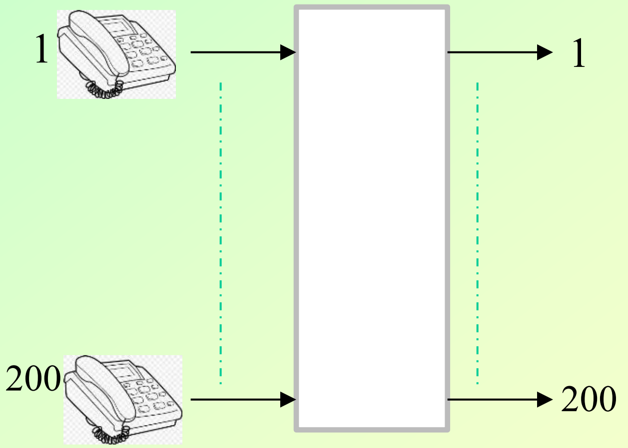
$$A_{ca} = A\,(1 - P_B)$$
$$= A \,.\, GoS$$

GOS = grade of service

Example IIa

Consider

- 200 telephone terminals, each with 15% utilization
- Dedicated service i.e., each terminal has an outgoing trunk link.



- Offered traffic A_{of} = 200 x 0.15 = 30 Er
- Carried traffic $A_{ca} = A_{of}$ = 30 Er
- Overflow of lost traffic A_l = 0.

Traffic Intensity Models

- **Erlang B Formula:** All blocked calls are cleared; **The most common**
  - Engset formula (probability of blocking in low density areas) is used where Erlang B model fails.
- **Extended Erlang B:** Similar to Erlang B, but considers a percentage of calls immediately presented to the system to see if they encounter blocking (a busy signal). The retry percentage can be specified.
- **Erlang C Formula:** Blocked calls delayed or held in the queue indefinitely
- **Poisson Formula:** Blocked calls held in queue for a limited time only. Also know as the delay formula. Therefore, time spent for waiting is more important than the probability of blocking
- **Binomial Formula:** Lost calls held

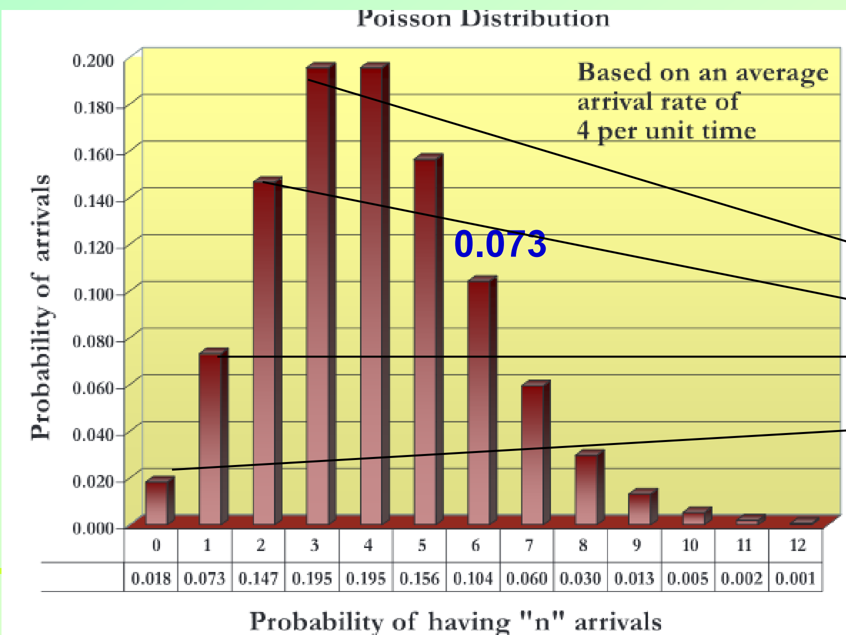
Traffic Intensity Models - Poisson

- Developed by the French mathematician Siméon-Denis Poisson (1781-1840), states that for non-overlapping events, arriving at an average rate, the probability of *x* arrivals in time *t* equals to:

$$P(k) = \frac{(E(n) \times t)^k e^{-E(n)t}}{k!}$$

Where $P(k)$ = Probability of arrivals
$E(n)$ = Average arrival rate
t = Average holding time
e = 2.71828

The formula allows calculation of the probability of having *n* arrivals, during some time interval, e.g., 1 sec., 1 min., etc.



The graph shows the probability of arrivals from 0 to 12, with an average arrival rate of 4.

The probability of having > 4 arrivals is:

1-(0.018+0.073+0.147+0.195+0.195) = 1 - (0.628), or 37.2%

Erlang B Model - Characteristics

Provides the **probability of blockage** at the switch due to congestion. Assumptions:

- No waiting is allowed (lost calls are cleared) **(I.e., they disappear from the system. This assumption is valid for systems that can overflow blocked calls onto another trunk (e.g. a high usage trunk)**
- Several identical servers process customers in parallel
- Limited No. of trunk (or serving channels)
- Memory-less, channel requests at any time
- The probability of a user occupying a channel is based on exponential distribution
- Calls arrival rate at the network = Poisson process (the holding time or duration of the call has exponentially distribution)
- Analyze using Markov Process of $n(t)$ – number of customers in the system at time t

Probability of Blocking P_B

- Equations for P_B, depend on assumption of what happens to calls that are blocked.
  - Lost Calls Cleared
    - Assume that blocked calls are cleared (lost from the system. This assumption is valid for systems that can overflow blocked calls onto another trunk (e.g., a high usage trunk)

$$A = A_{ca} / (1 - P_B)$$

  - Lost Calls Returning
    - Assume that blocked calls are re-tried until they are successfully carried. This assumption is valid for PBXs and corporate tie lines.

$$A \text{ > or = } A_{Ca}$$

Probability of Blocking P_B

In MATLAB, use Erlangb (C,A)

- Lost calls cleared
- Poisson arrival
- Call holding times are of fixed length or are exponentially distributed
- Also known as the **Erlang-B formula** given by:

$$P_B(C, A) = \frac{\dfrac{A^C}{C!}}{\sum_{k=0}^{C} \dfrac{A^k}{k!}}$$

where
- A is the traffic intensity
- C is the number of channels (lines or servers)

Expressed recursively in a form that is used to calculate tables of the Erlang B formula as

$$P_B(0, A) = 1$$

$$P_B(C, A) = \frac{A P_B(C-1, A)}{C + A P_B(C-1, A)}$$

Probability of Blocking P_B - *contd.*

The carried traffic is $A_{ca} = A\ \underbrace{[1 - P_B]}_{\text{GoS}}$

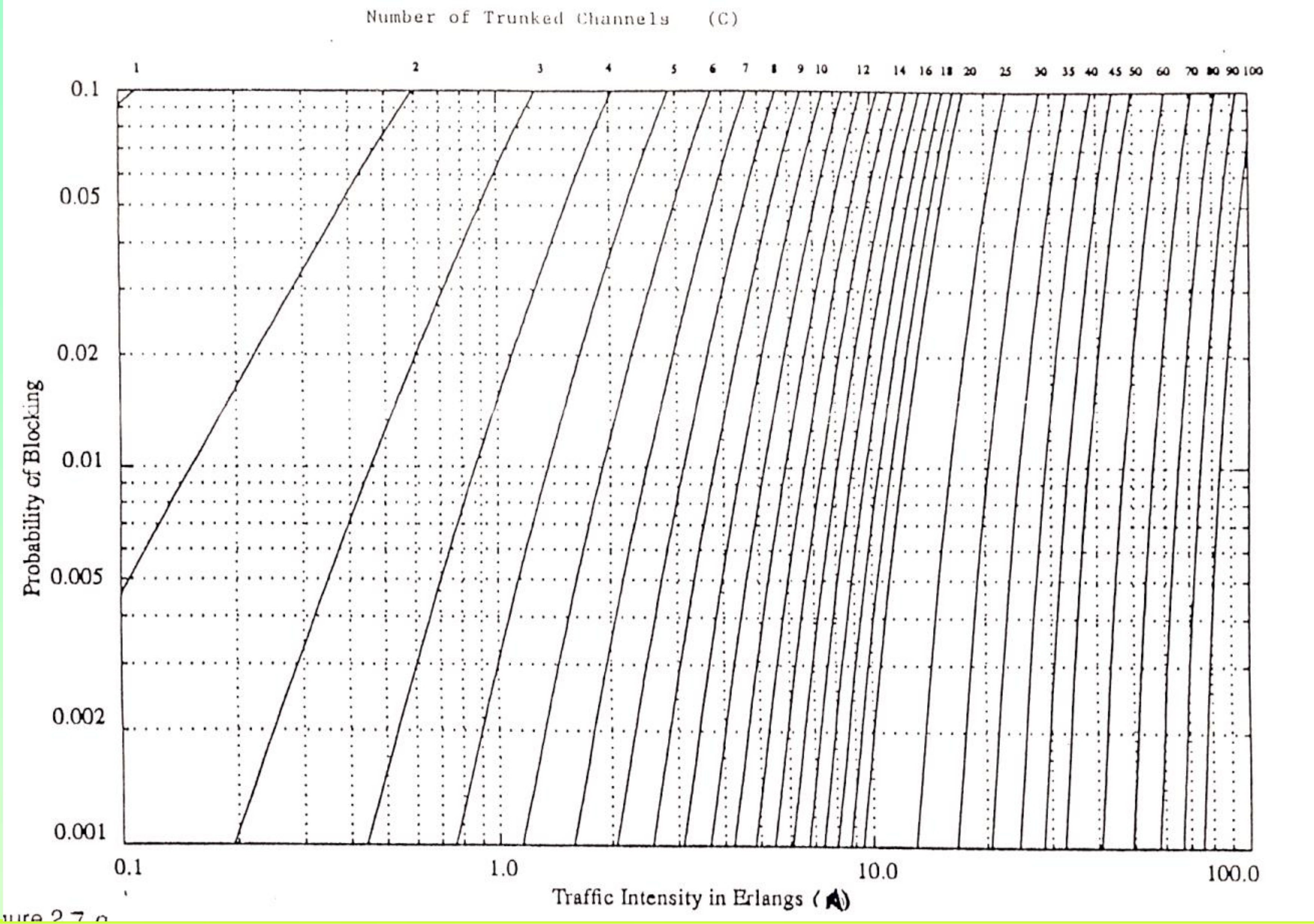
* The start-up systems usually begins with a GoS of 0.02 (2% of the blocking probability) rising to 0.5 as the system grows.

* If more subscribers are allowed in the system the blocking probability may reach unacceptable values.

Erlang B Table

Number of channels *C*	Traffic Intensity *A* (Erlangs)			
	QoS=0.01	QoS= 0.005	QoS= 0.002	Qos= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.9	0.762
10	4.46	3.96	3.43	3.09
20	12	11.1	10.1	9.41
24	15.3	14.2	13	12.2
40	29	27.3	25.7	24.5
70	56.1	53.7	51	49.2
100	84.1	80.9	77.4	75.2

Erlang B Chart



Example III

A single GSM service provider support 10 digital speech channels. Assume the probability of blocking is 1.0%. From the Erlang B chart find the traffic intensity. How many 3 minutes of calls does this represent?

Solution:

From the Erlang B Chart the traffic intensity = ~5 Erlangs

$A_I = \mu H$

$\mu = A_I / H = 5/(3 \text{ mins}/60) = 100$ calls

Example IV

A telephone switching board at the UNN can handle 120 phones.
Assuming the followings, determine the outgoing traffic intensity and
The number of channels.

- On average 5 calls/hour per phone,
- Average call duration time = 4 minutes,
- 60% of all calls made are external.
- QoS = 0.9%

Solution:

$A_T = U.\mu.H$

μ*U = (120 call*5 calls/hour)*60% = 360 call/hour

H = 4 mins/call

Therefore A_I =360 * 4 * (1 hour/60 mins) = 24 Erlangs.

Thus 24 hours of circuit talk time is required for every hour of elapsed time

-No. of channels C from Erlang B chart = ~ 34

Example V

- Consider a telephone switched board with 120 phones. Assuming the number of call is 3/hour/line, the average call duration is 4 minutes, and 55 % of all call are made external via a T-1 trunk (24 channels) to the PSTN. Determine carried traffic and channel usage.

Solution:

- Offered traffic $A = \mu \times H$ = (150 phones x 3 calls/hr x 58%) x (4 mins./call) x (1 hour/60 mins.) = 17.4 Erlangs
- Blocking Probability P_B, C = 24 and A = 17.4, therefore from the Erlang B Chart or formula P_B = 0.03
- Carried Traffic, $A_{ca} = A\,(1- P_B)$= 17.4 (1-.03)=16.9 Erlangs
- Channel usage $\eta = A_{ca} / C$ = 16.9/24 = 0.7 or 70%

  Note: 16.9 Erlangs of traffic attempts to go across the T1 trunk and 0.5 Erlang is blocked.

Circuit Utilization

Also known as Circuit Efficiency:

- The proportion of the time the circuit is busy, or
- The average proportion of time each circuit in a group is busy.

$$CU = A_{ca} \,/\, \text{No. of trunks} \quad \%$$

Example VI

Over an observation time interval of 30 mins, 50 subscribers make calls. The total duration of the calls is 5000 seconds. Calculate the:

(i) Load offered to the network by the subscribers

(ii) Average subscriber traffic.

Solution:

The mean arrival rate = 50/30 = 1.7 calls/min

The mean holding time = 5000/ (50 x 60) = 1.7 mins/call

(i) Load offered = 1.7 x 1.7 = 3.4 Er

(ii) Average subscriber traffic = 3.4/50 = 0.07 Er.

Example VII

- Consider a PSTN which receives 72 calls/hr. Determine the arrival rate λ per unit time, the service rate per unit time and the total system utilization for 2 min. of service time.

Solution

arrival rate λ per unit time = 72/60 (min) = 1.2 call per min

service rate per unit time = 60 (min) / 2 = 30 per hour

= 30 / 60 = 0.5 per min.

total system utilization ρ_{su} = 1.2 / 0.5 **= 2.4**

This value identifies the minimum number of servers (lines, channels) needed.

You can't have 2.4 people, thus the minimum number of servers = 3

Example VII

Consider a 7-cell cellular system, where:

- Total available channels: 395
- Each subscriber generates 0.03 Erlang
- Average holding time: 120 sec.
- System area: 1200 miles^2
- Grade of service: 2%

Determine:

(i) The number of channels per cell

(ii) The number of subscribers served by the system

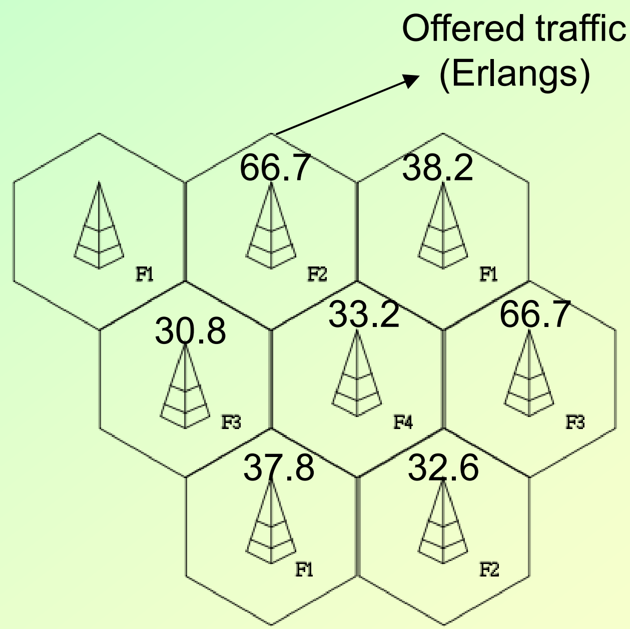
(iii) The average number of subscribers per channel

(iv) The number of calls per hour supported by the system

(v) The subscriber density per miles^2

(vi) The call density per miles^2

(vii) The cell radius in miles



Example VII - Solution

Parts (a) and (b)

Cell number	**Traffic (Erlang)** ***A***	**No. of channels** ***C* –**	**No. of subs./cell** $N_{sub/cell}$	**No. of calls/cell** $N_{calls/cell}$	**Channel utilisation**
1	30.8	40	1026.7	924	0.77
2	66.7	78	2223.3	2001	0.86
3	48.6	59	1620	1458	0.82
4	33.2	43	1106.7	996	0.77
5	38.2	48	1273.3	1146	0.80
6	37.8	48	1260	1143	0.79
7	32.6	42	1087.7	978	0.78
Total	**287.9**	**358**	**9596.7**	**8637**	
		Using Erlang B at 2%	$A/0.03$	$N_{sub/cell}$ x0.9	A/C

Example VII - Solution

(c) Average number of subscribers/channel 9597/358 = 26.8

(d) Number of calls supported in every cell:

$$A = \lambda H \Rightarrow 0.03 = \lambda \times 120 \text{ sec}$$

The average calls/sec => λ= 0.03/120 = 0.00025 calls/sec

= 0.0025 x 3600 = 0.9 Calls/hr/user

The number of calls supported in cell (1) per hour

= 1026.7 x 0.9 = 924 calls/hour

See table for the rest of the cells.

(e) Subscriber density per mile^2 = 9597 / 1200 ≈ 8 subscribers/mile^2

(f) The call density 8637 call/ 1200 $^{\text{mile2}}$ = 7.2 calls per mile^2/hour

(g) Cell radius in miles:

Area per cell = Total area / #cells = 1200 / 7 = 171.4 miles2

Hexagon-cell area = 2.6 R^2 -- > 171.4 = 2.6 R^2

=> Cell-Radius R= 8.12 miles

Example VIII - Problem

- In a cellular system we have:
  - The average No. of calls/hour/cell = 3000
  - The average call time: 1.76 mins
  - P_B = 2%

  Find the offered traffic, and the maximum number of channels in the system

  If the average No. of calls/hour/cell = 3072 with P_B = 5%, determine the maximum number of channels in the system

Example VIII - Solution

- Average number of call/hour/cell = A = μ *H
  - = 3000 (Call/Hour)* 1.76 (min/Call)
  - = 5280 min/Hour
  - In Erlang = 5280 min/Hour * 1 Hour/60 min
  - = 88 Erlang
  - Therefore, for A of 88 Erlang and Pb of 2%, from the Erlang B-Chart we have the offered traffic channel = 100.

Traffic Engineering

- The probability that all servers are idle

$$P_o = \left[\sum_{k=0}^{C-1} \frac{\rho_{su}{}^{k}}{k!} + \frac{\rho_{su}{}^{C}}{C!\,(1 - \rho_{su}/C)} \right]$$

- The probability that all servers are busy

$$P_b = \frac{P_0 \rho_{su}{}^{C}}{C!\,(1 - \rho_{su}/C)}$$

- The average number of callers in the queue

$$L_q = \frac{P_b \rho_{su}}{C - \rho_{su}}$$

Traffic Engineering

- The average number of callers in the system

$$L = L_q + \rho_{su}$$

- The average wait time in the queue

$$T_q = \frac{L_q}{\lambda}$$

- The average flow time through the system

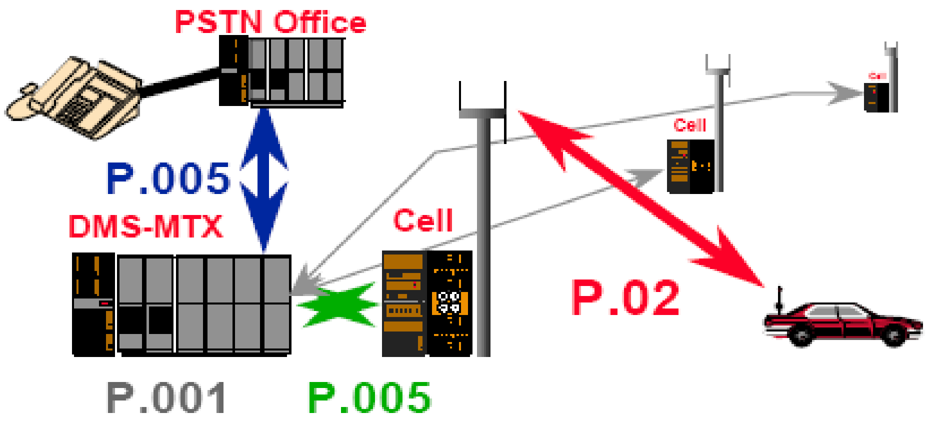
$$T = \frac{L}{\lambda}$$

Principles of Traffic Engineering
Blocking Probability / Grade of Service

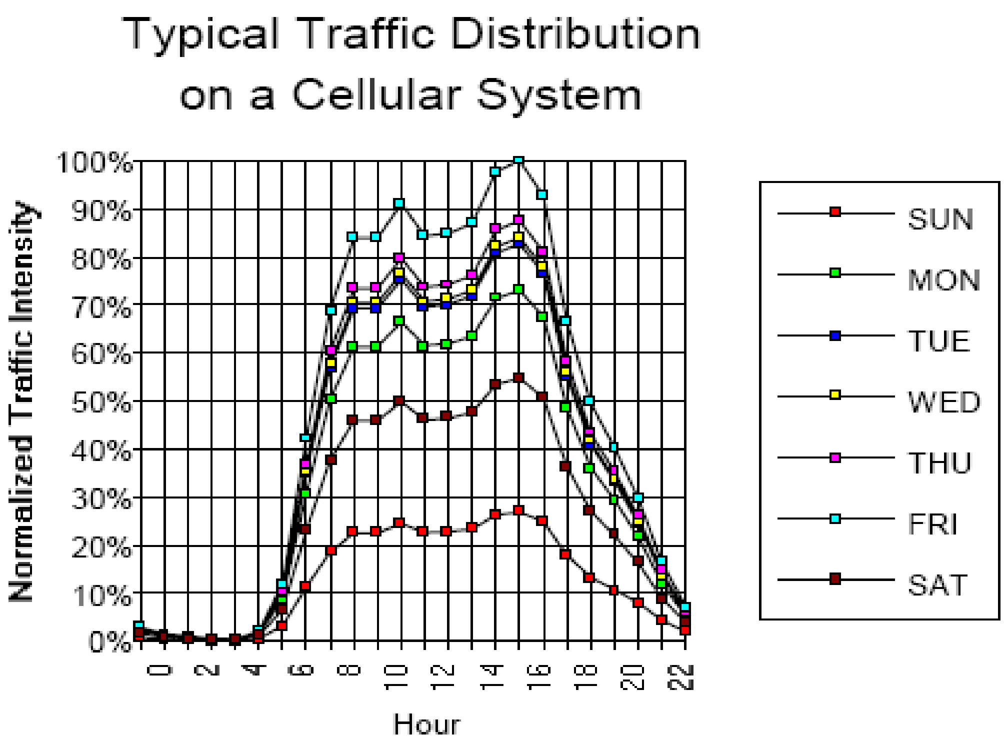
- Blocking is inability to get a circuit when one is needed
- Probability of Blocking is the likelihood that blocking will happen
- In principle, blocking can occur anywhere in a wireless system:
  - not enough radios, the cell is full
  - not enough paths between cell site and switch
  - not enough paths through the switching complex
  - not enough trunks from switch to PSTN
- Blocking probability is usually expressed as a percentage using a "shorthand" notation:
  - **P.02** is 2% probability, etc.
  - Blocking probability sometimes is called "**G**rade **O**f **S**ervice"
- Most blocking in cellular systems occurs at the radio level.
  - P.02 is a common goal at the radio level in a system

Typical Wireless System

Design Blocking Probabilities



Wireless Traffic Variation with Time: A Cellular Example



Actual traffic from a cellular system in the mid-south USA in summer 1992. This system had 45 cells and served an area of approximately 1,000,000 population.

- Peak traffic on cellular systems is usually daytime business-related traffic; on PCS systems, evening traffic becomes much more important and may actually contain the system busy hour
- Evening taper is more gradual than morning rise
- Wireless systems for PCS and LEC-displacement have peaks of residential traffic during early evening hours, like wireline systems
- Friday is the busiest day, followed by other weekdays in backwards order, then Saturday, then Sunday
- **There are seasonal and annual variations, as well as long term growth trends**

Profile of Typical Cellular Usage

Offered Traffic, mE per subscriber in busy hour	25 mE
Number of call attempts per subscriber in busy hour	1.667
Average Call Duration	150 sec. (41.7 mE)
Mobile originated calls	
proportion of total calls on system	87 %
successful calls	70 %
Calls not answered	15 %
calls to a busy line	15 %
Mobile terminated calls	
proportion of total calls on system	13 %
successful calls	15 %
Calls not answered	10 %
paging requests not answered	75 %
Number of handoffs per call	0.87
Registration attempts per subscriber during busy hour	2

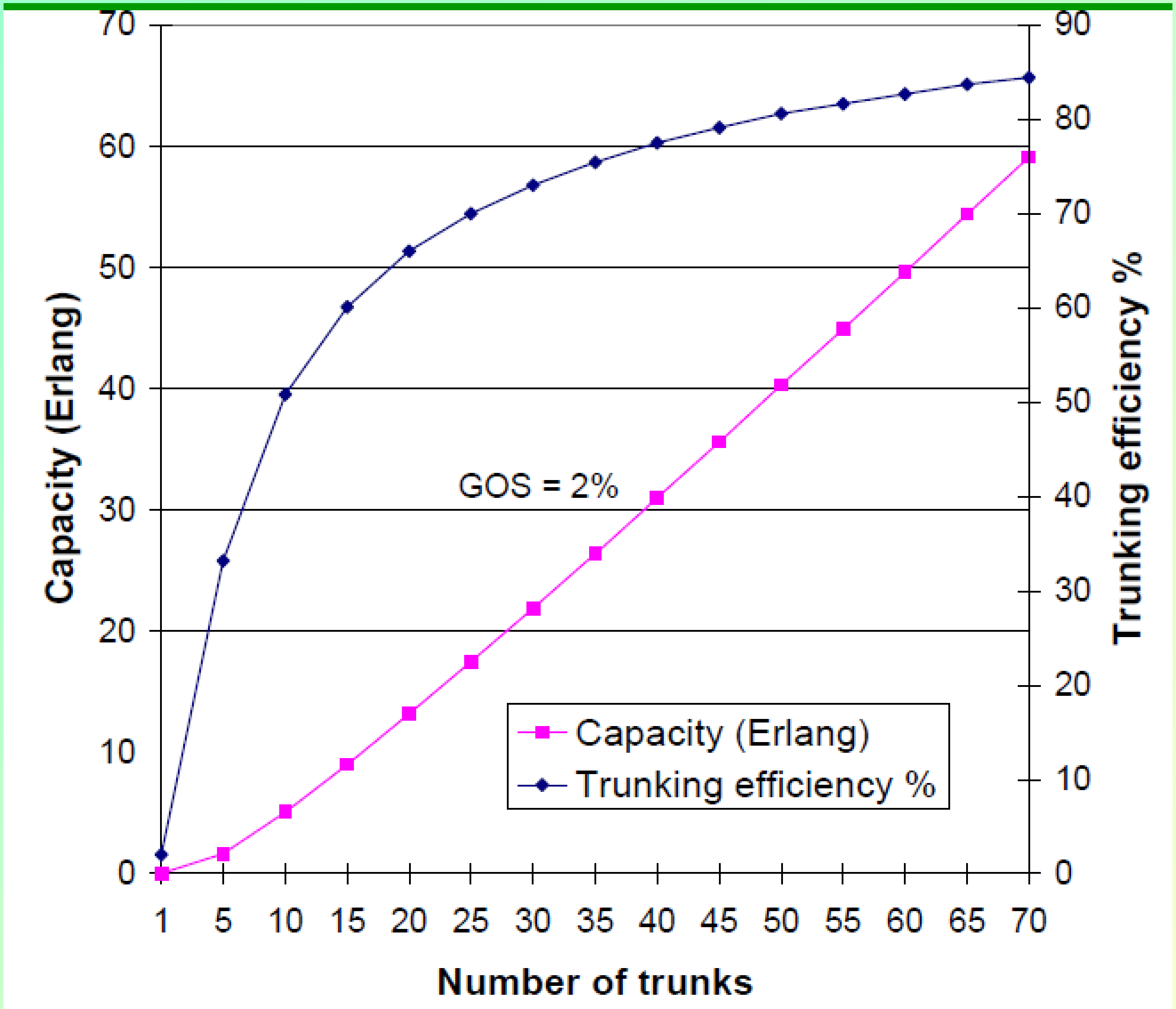
Example IX

- As a manger of a growing call center, you are looking at obtaining additional phones for the PBX since customers have complained about long hold times. On average, there are 4 incoming calls per hour on each phone. The traffic study you requested from the Ameritech CO shows that on average, your company receives 480 calls/hour. How many phones do you need to order? Currently there are 100 phones connected to the PBX for the customer service agents

Solution

- μ is the average call arrival rate= 480calls/hour (from traffic study)
  - **μ = phones x calls/hr**
  - **480 = *N* x 4 calls/hour**
  - ***N* = 480/4 = 120 phones**
  - **So the manager needs to order 120-100 = 20 more phones and hire new customer service reps as well**

Traffic Efficiency



The efficiency of the channel usage is

$$\eta = \frac{A_{ca}}{C}$$

Saleh Faruque. Cellular Mobile Systems Engineering. *Mobile Communication Series. Artech House Publishers. ISBN 0-89006-518-7.1996.*

Spectrum Efficiency

1- Spectrum efficiency

It is a measure of how efficiently frequency, time and space are used:

SE = Carried traffic A_{ca} / System bandwidth / Cell area (Erlang/MHZ/km^2)

System bandwidth = (Bandwidth/channel).(No. channel/cell).(Cluster size)

Note:
- SE decreases with the cluster size.
- But, system performance (outage probability or it error rate experienced by the user), improves with the increasing re-use distance, therefore improves with the cluster size.
- Hence, a trade-off between SE and system performance.

Trunking and Economic Efficiencies

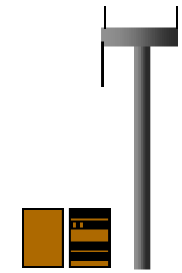
2- Trunking efficiency

Measures the number of subscribers that each channel in every cell can accommodate

3- Economic efficiency

It measures how affordable is the mobile service to users and the cellular operators.

No. of Trunk Vs. Utilization Efficiency



- Imagine a cell site with *just **one** voice channel*. At a **P.02** Grade of Service, how much traffic could it carry?
  - The trunk can only be used 2% of the time, otherwise the blocking will be worse than 2%.
  - 98% *availability* forces 98% *idleness*. It can only carry .02 Erlangs. Efficiency 2%!

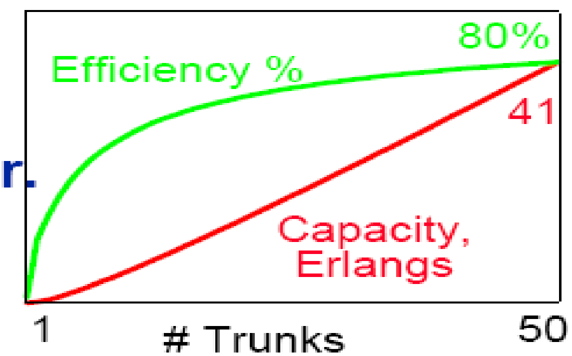
- Adding just one trunk relieves things greatly. Now we can use trunk 1 heavily, with trunk 2 handling the overflow. Efficiency rises to 11%

Erlang-B P.02 GOS

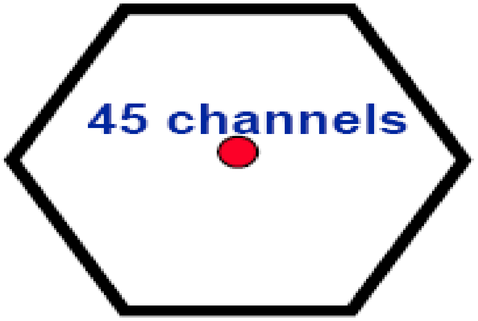
Trks	Erl	Eff%
1	0.02	2%
2	0.22	11%

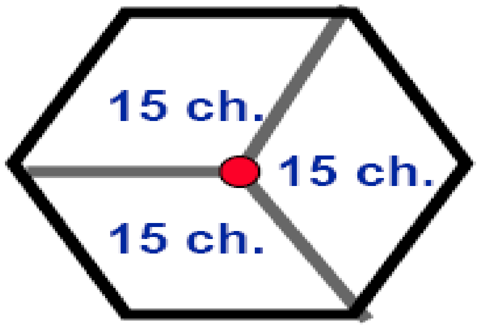
The Principle of Trunking Efficiency

- **For a given grade of service, trunk utilization efficiency increases as the number of trunks in the pool grows larger.**
  - For trunk groups of several hundred, utilization approaches 100%.



Trunking Efficiency
An Important Cellular Consideration





- Busy cellular systems often use sectorized cells
  - A cell's coverage area is divided into several "sectors" using directional antennas
    - 3-sector (120-degrees)
    - 6-sector (60-degrees)
  - radio channels assigned per sector
- Capacity of a sectorized cell is less than capacity of an omni cell with same total number of channels
  - 45 channels: 35.61 Erlangs
  - 3 x 15 channels: 3 x 9.01 Erl. = 27.03 Erlangs
- Why would anyone sectorize?
  - Sectorization eases frequency reuse more than it hurts capacity

Comparison of Wireless System Capacities

	800 Cellular (A,B)			1900 PCS (A, B, C)			1900 PCS (D, E, F)		
Fwd/Rev Spectrum kHz.	12,500	12,500	12,500	15,000	15,000	15,000	5,000	5,000	5,000
Technology	AMPS	TDMA	CDMA	TDMA	GSM	CDMA	TDMA	GSM	CDMA
Req'd C/I or Eb/No, db	17	17	6	17	12	6	17	12	6
Freq Reuse Factor, N	7	7	1	7	4	1	7	4	1
RF Signal BW, kHz	30	30	1250	30	200	1250	30	200	1250
Total # RF Carriers	416	416	9	500	75	11	166	25	3
RF Sigs. per cell @N	59	59	9	71	18	11	23	6	3
# Sectors per cell	3	3	3	3	3	3	3	3	3
#CCH per sector	1	1	0	1	0	0	1	0	0
RF Signals per sector	18	18	9	22	6	11	6	2	3
Voicepaths/RF signal	1	3	22	3	8	22	3	8	22
SH average links used	1	1	1.66	1	1	1.66	1	1	1.66
Unique Voicepaths/carrier	1	3	13.253	3	8	13.253	3	8	13.253
Voicepaths/Sector	18	54	198	66	48	242	18	16	66
Unique Voicepaths/Sector	18	54	119	66	48	145	18	16	39
P.02 Erlangs per sector	11.5	44	105.5	55.3	38.4	130.9	11.5	9.83	30.1
P.02 Erlangs per site	34.5	132	316.5	165.9	115.2	392.7	34.5	29.49	90.3
Capacity vs. AMPS800	**1**	**3.8**	**9.2**	**4.8**	**3.3**	**11.4**	**1.0**	**0.9**	**2.6**

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- **Next lecture: Propagation**