Wireless Communication Systems

Modul 10 Celluar Traffic (Teletraffic)

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Bandung – 2015

Teletraffic engineering

- Rekayasa trafik adalah bidang penting dalam perencanaan jaringan telekomunikasi untuk memastikan bahwa **biaya jaringan** dapat **diminimalkan** tanpa mengorbankan kualitas layanan (<u>quality of service</u>) ke pengguna

- Aspek penting dari trafik seluler meliputi :
  - kapasitas trafik dan ukuran sel,
  - efisiensi spektral dan sektorisasi,
  - kapasitas trafik vs coverage dan analisis holding time (waktu pendudukan)

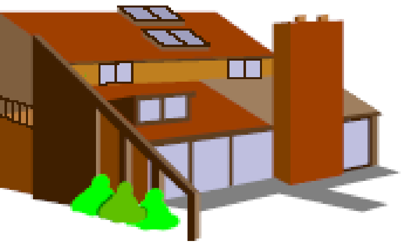
Who needs Teletraffic Engineering?

- Telecommunications administrations
- Companies involved in the manufacture of telecommunications equipment
- Companies involved in the development of value added services in the telecommunications industry
- Corporate businesses who have extensive private communications networks for internal use or for shared use with other companies.
- Government communications network groups
- Military

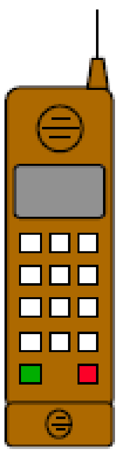
What is the role of Teletraffic Engineering today?

- **There are three main thrusts for Teletraffic Engineering today:**
- **Design (for development and manufacture)**
- **Dimensioning (for planning and installation)**
- **Operations (network traffic management)**

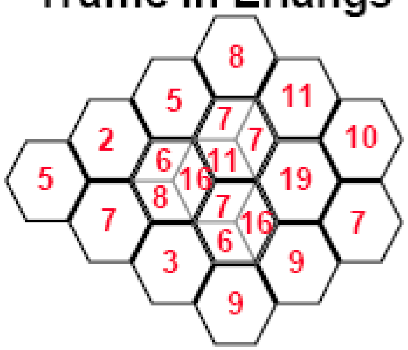
Differences Wireline & Wireless Traffic

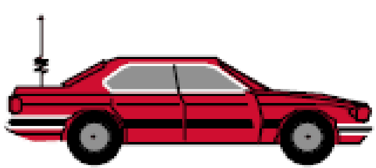


- Wireline telephone systems have a big advantage in traffic planning.
  - They know the addresses where their customers generate the traffic!
- Wireless systems have to ***guess*** where the customers will be next
  - on **existing** systems, use measured traffic data by sector and cell
    - analyze past trends
    - compare subscriber forecast
    - trend into future, find overloads
  - for **new** systems or new cells, we must use all available clues



Existing System Traffic In Erlangs

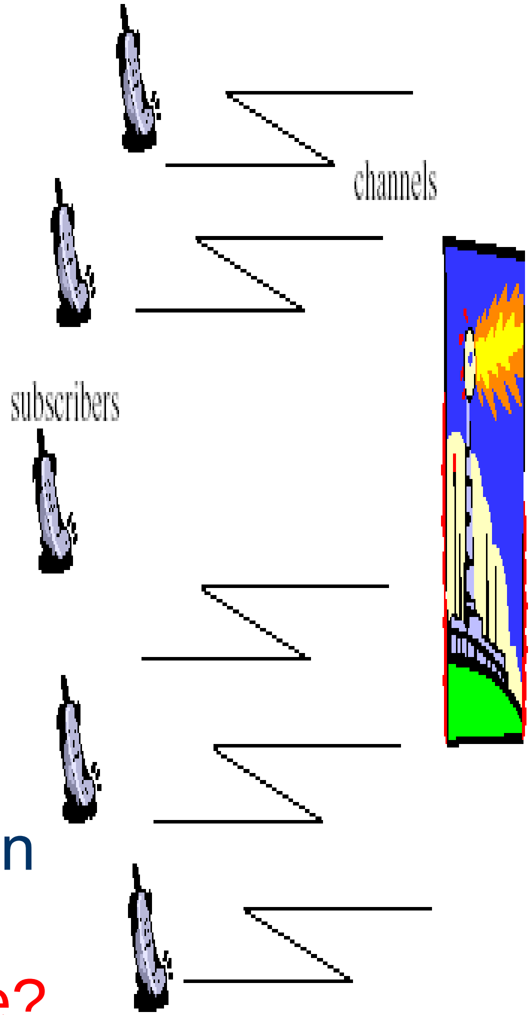




Problems of Cellular Traffic

How many channels are needed?
How many subscribers can the system handle?
What is the grade of service?
How many subscribers?
How often do they make/receive calls?
How long do the calls last?
How many channels are available?

- What is the probability that there will be no channel when one is needed (“blocking”)?
- How many channels do I need to stay within a prescribed blocking probability?
- How many subscribers can I accommodate?



Traffic Planning Clues for a New System

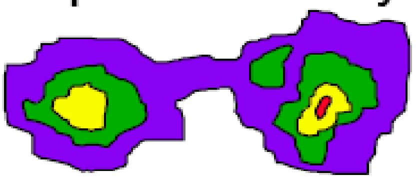
Traffic Clues

27 mE/Sub in BH

103,550 Subscribers
1,239,171 Market Population

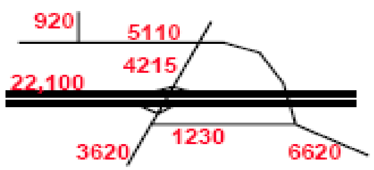
adding 4,350 subs/month

Population Density



new
Shopping Center

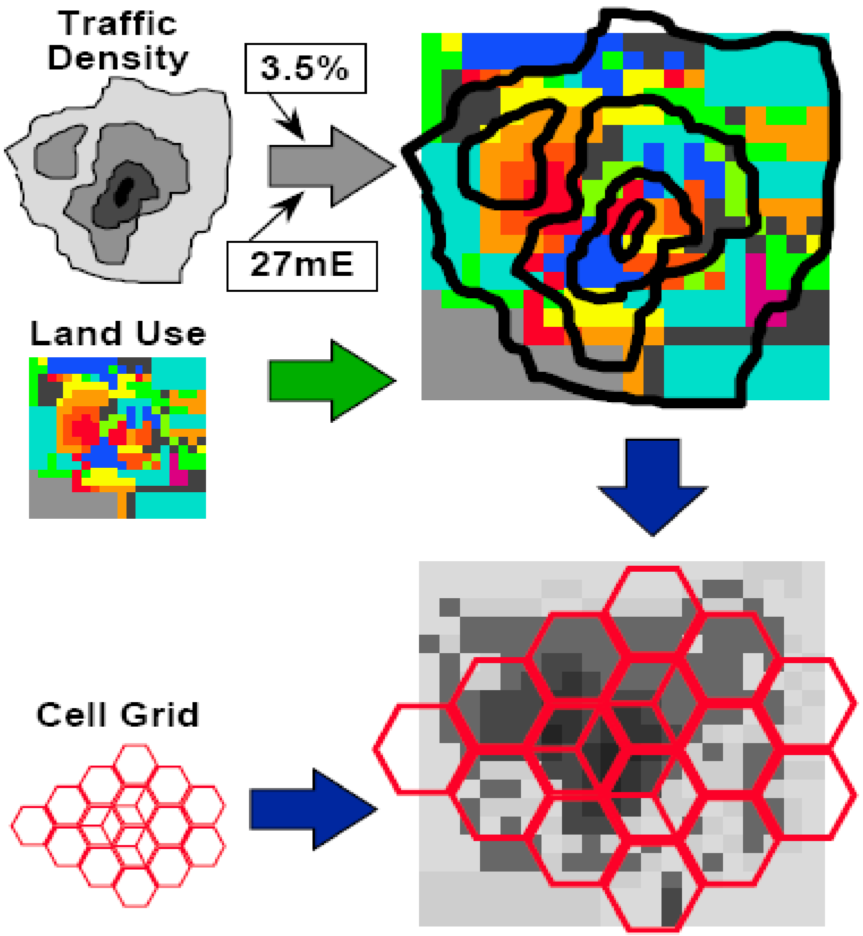
Vehicular Traffic



Land Use
Databases

- Subscriber Profiles:
  - Busy Hour Usage, Call Attempts, etc.
- Market Penetration:
  - # Subscribers/Market Population
  - use Sales forecasts, usage forecasts
- Population Density
  - Geographic Distribution
- Construction Activity
- Vehicular Traffic Data
  - Vehicle counts on roads
  - Calculations of density on major roadways from knowledge of vehicle movement, spacing, market penetration
- Land Use Database: Area Profiles
- Aerial Photographs: Count Vehicles!

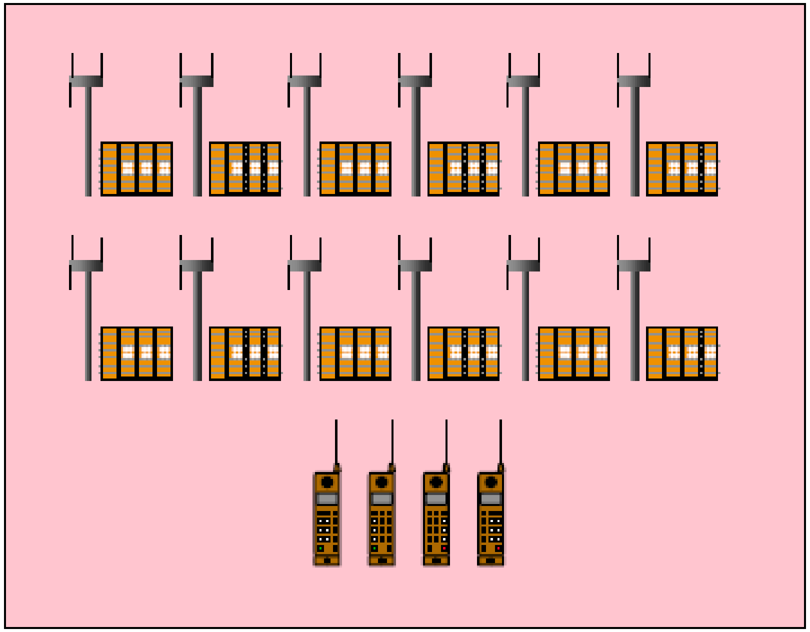
Methodical Estimation of Required Trunks

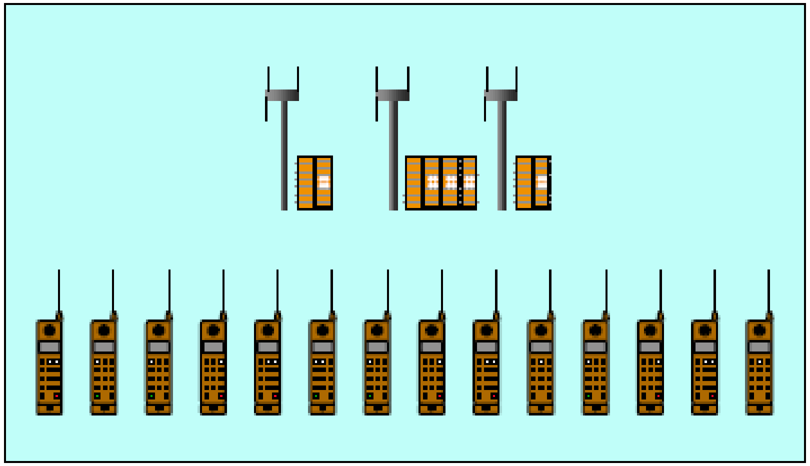


Modern propagation prediction tools allow experimentation and estimation of traffic levels

- Estimate total overall traffic from subscriber forecasts
- Form traffic density outlines from market knowledge, forecasts
- Overlay traffic density on land use data; weight by land use
- Accumulate intercepted traffic into serving cells,
  - obtain Erlangs per cell & sector
- From tables, determine number of trunks required per cell/sector
- Modern software tools automate major parts of this process

A Game of Avoiding Extremes



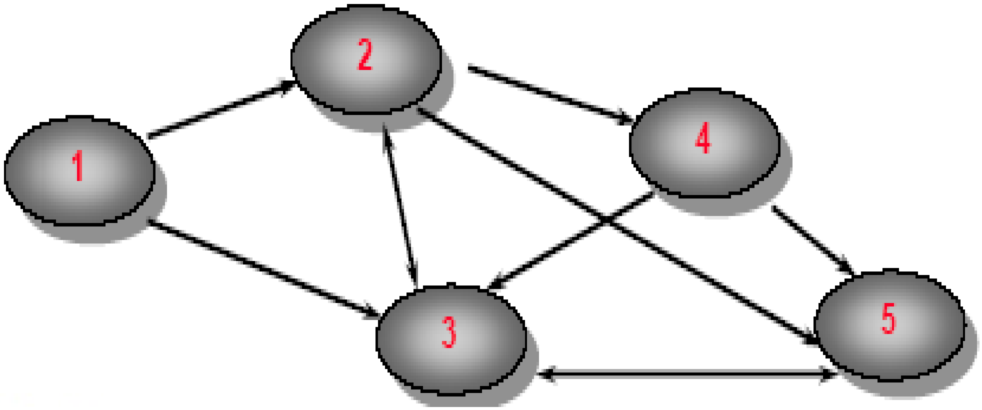


The traffic engineer must walk a fine line between two problems:

- **Overdimensioning**
  - **too much cost**
  - insufficient resources to construct
  - traffic revenue is too low to support costs
  - very poor economic efficiency!
- **Underdimensioning**
  - **blocking**
  - poor technical performance (**interference**)
  - capacity for billable revenue is low
  - revenue is low due to poor quality
  - users unhappy, cancel service
  - very poor economic efficiency!

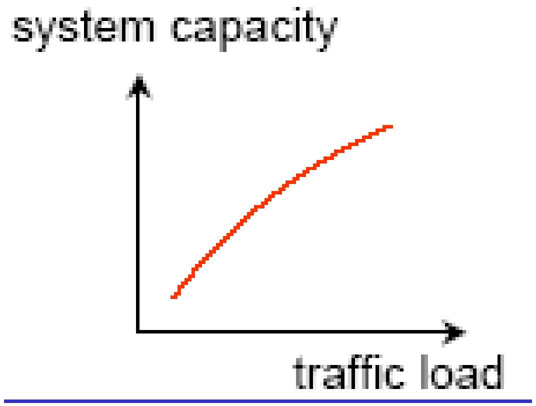
What is Teletraffic Engineering?

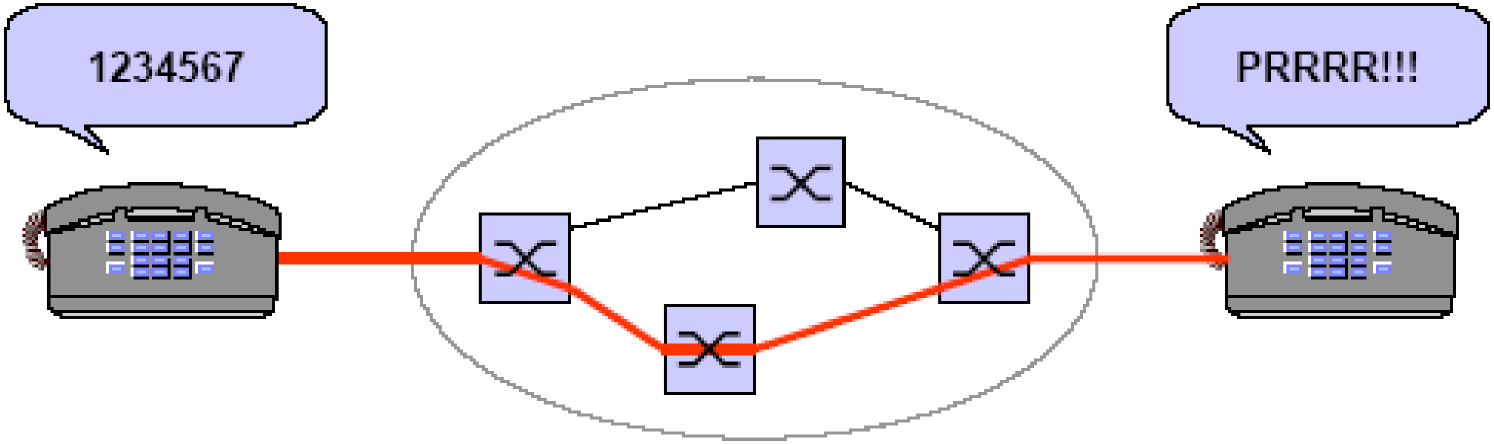
- Teletraffic Engineering involves the mathematical modelling of communications systems and networks.
- The objectives of teletraffic engineering are to determine methods of designing communications networks and services at reasonable cost.
- This must be done in such a way as to satisfy quality of service standards and the needs of network subscribers.



Introduction to traditional teletraffic theory

- General purpose: determine **relationships** between
- – quality of service
- – traffic load
- – system capacity
- • To describe the relationships quantitatively,
- **mathematical models** are needed





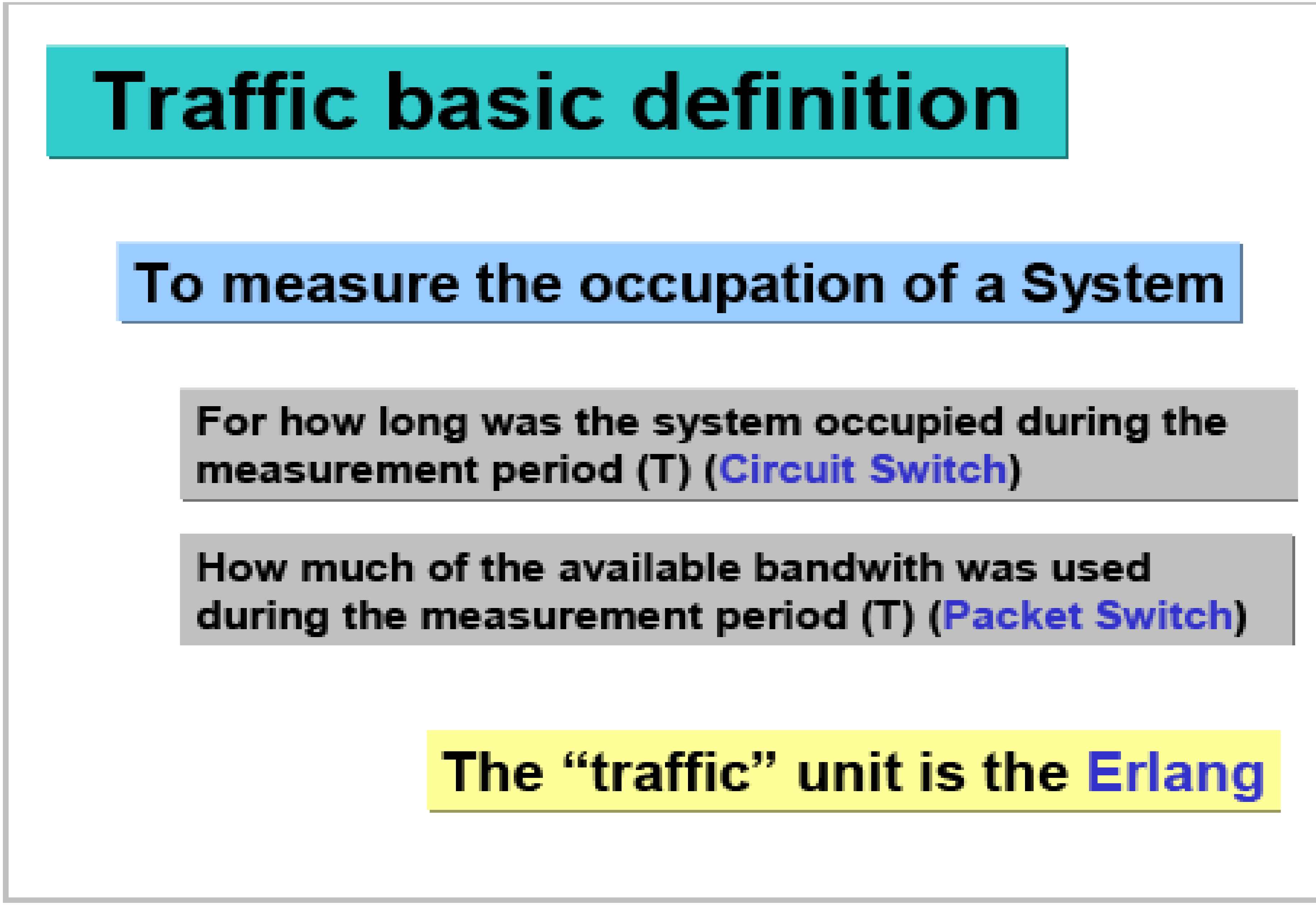


Fig. 1 Traffic basic definition

Traffic Measurement Periode

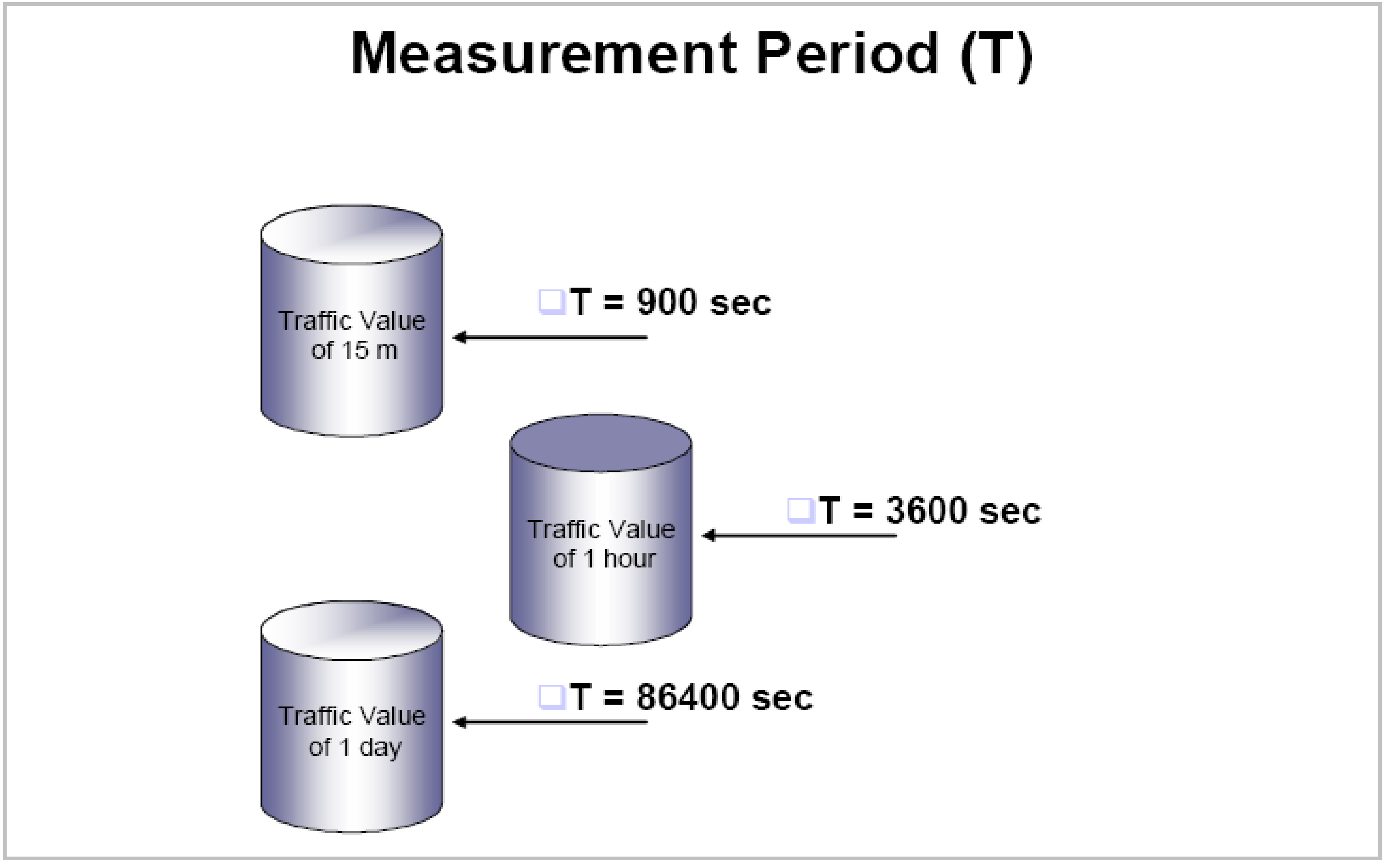


Fig. 5 Measurement period T

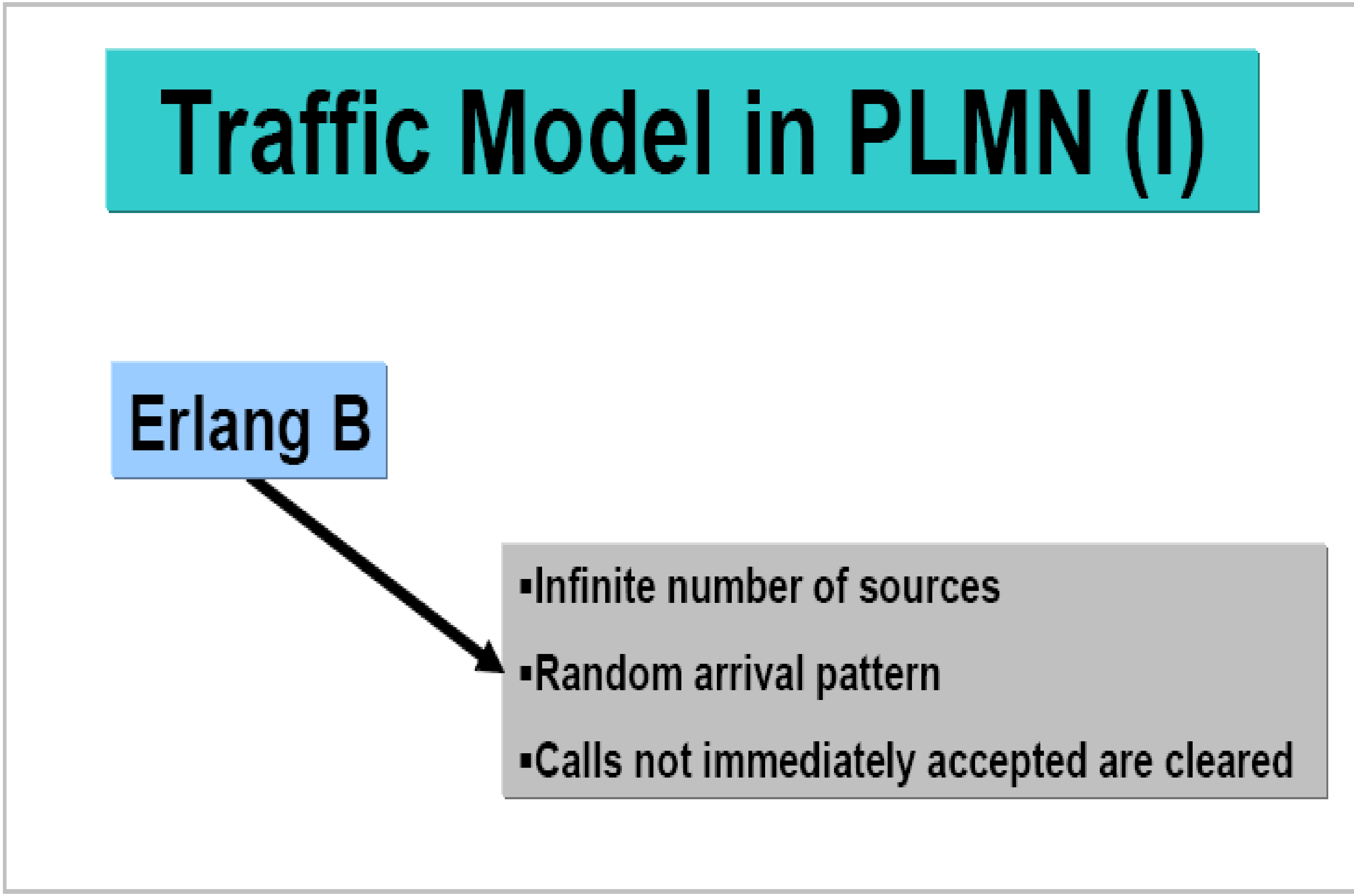


Fig. 2 Traffic model in a PLMN (I)

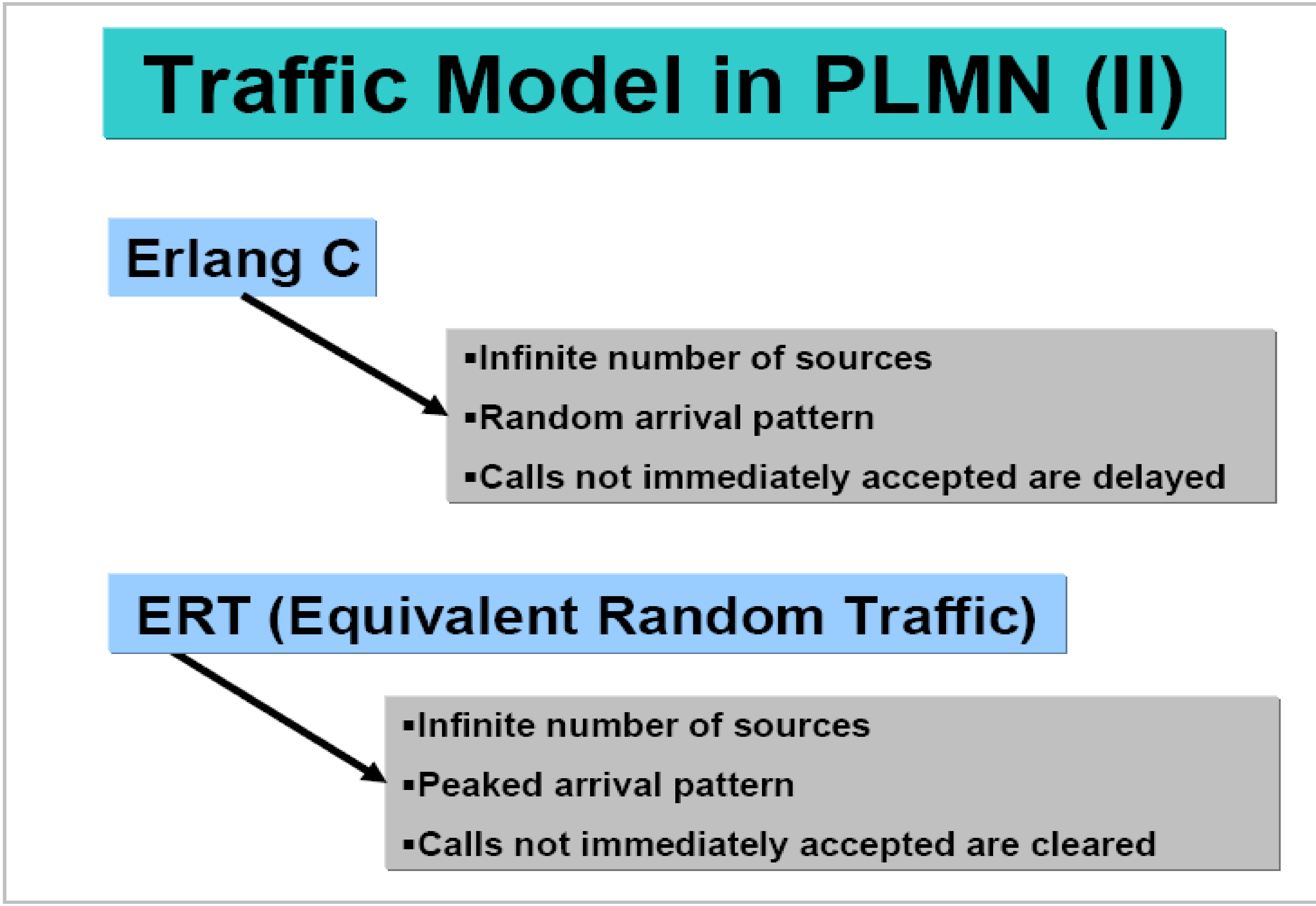
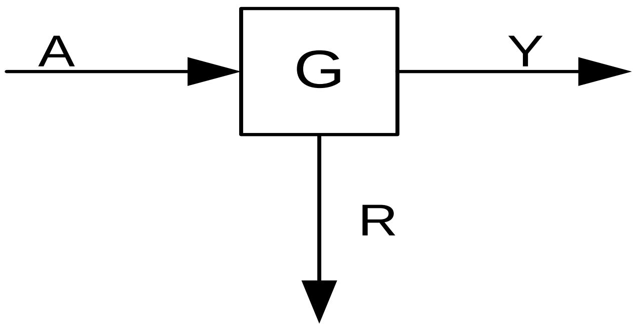


Fig. 3 Traffic model in a PLMN (II)

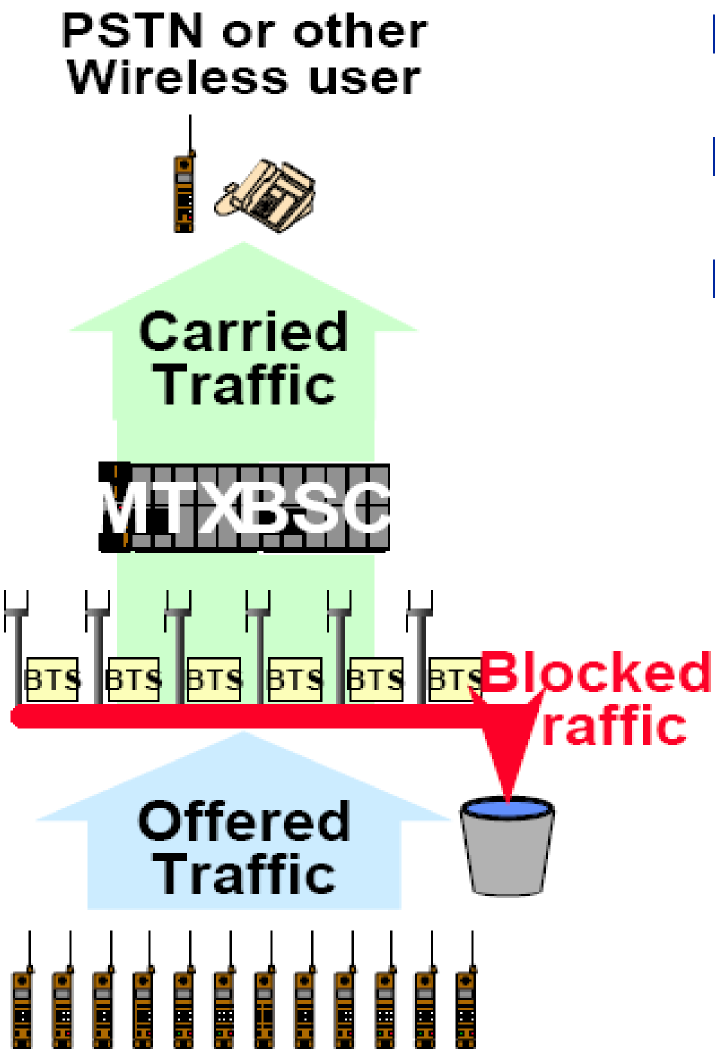
Macam-macam Trafik

1. ***Offered Traffic* (A)**
   Trafik yang ditawarkan atau yang mau masuk ke jaringan.
2. ***Carried Traffic* (Y)**
   Trafik yang dimuat atau yang mendapat saluran.
3. ***Lost Traffic* (R)**
   Trafik yang hilang atau yang tidak mendapat saluran.



G = elemen gandeng (switching network)

Offered And Carried Traffic



- *Offered traffic* is what users attempt to originate
- *Carried traffic* is the traffic actually successfully handled by the system
- *Blocked traffic* is the traffic that could not be handled
  - Since blocked call attempts never materialize, blocked traffic must be ***estimated*** based on number of blocked attempts and average duration of successful calls

Offered Traffic =
Carried Traffic + Blocked Traffic

$$T_{Off} = N_{CA} \times T_{CD}$$

T_{Off} = Offered traffic

N_{CA} = Number of call attempts

T_{CD} = Average call duration

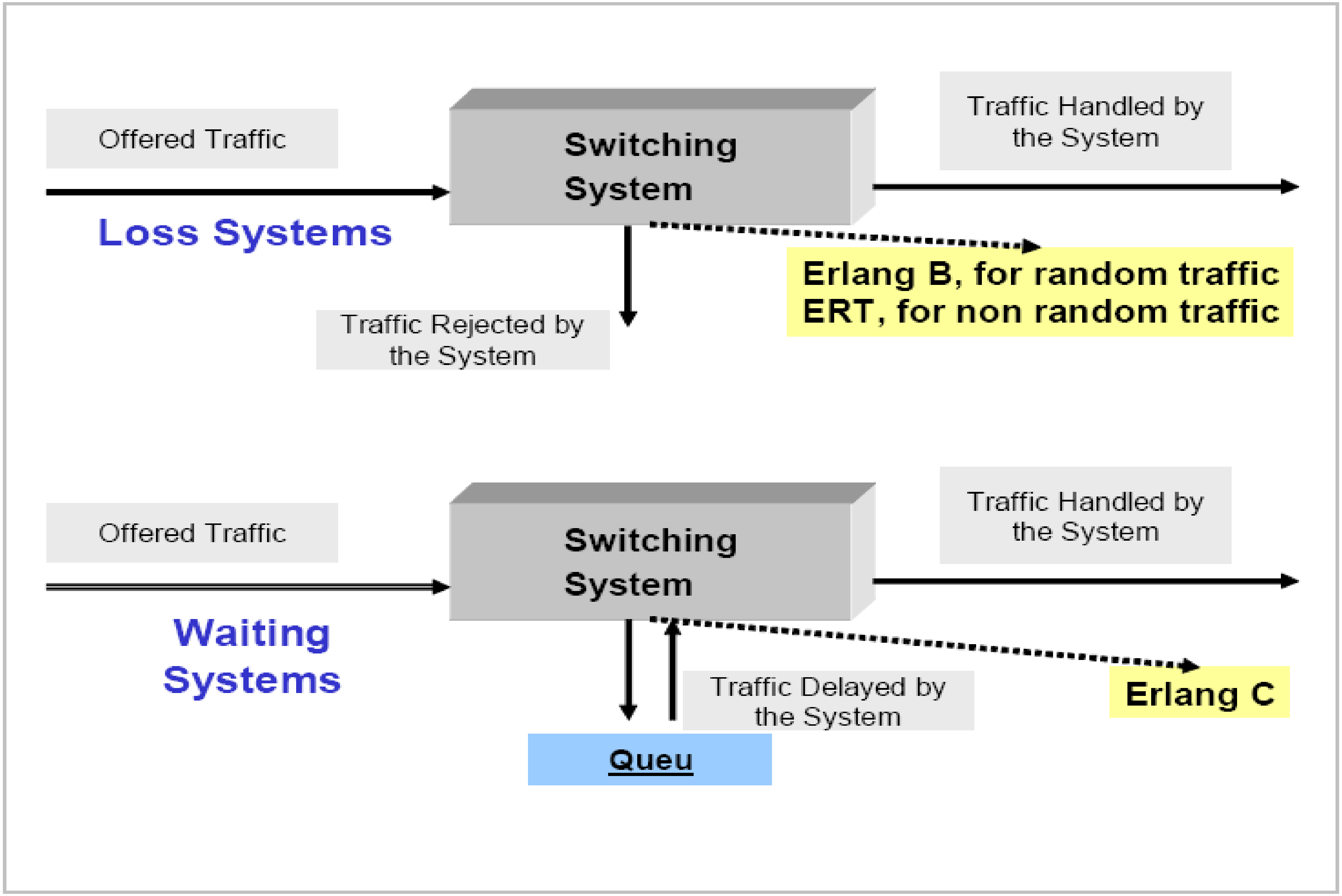
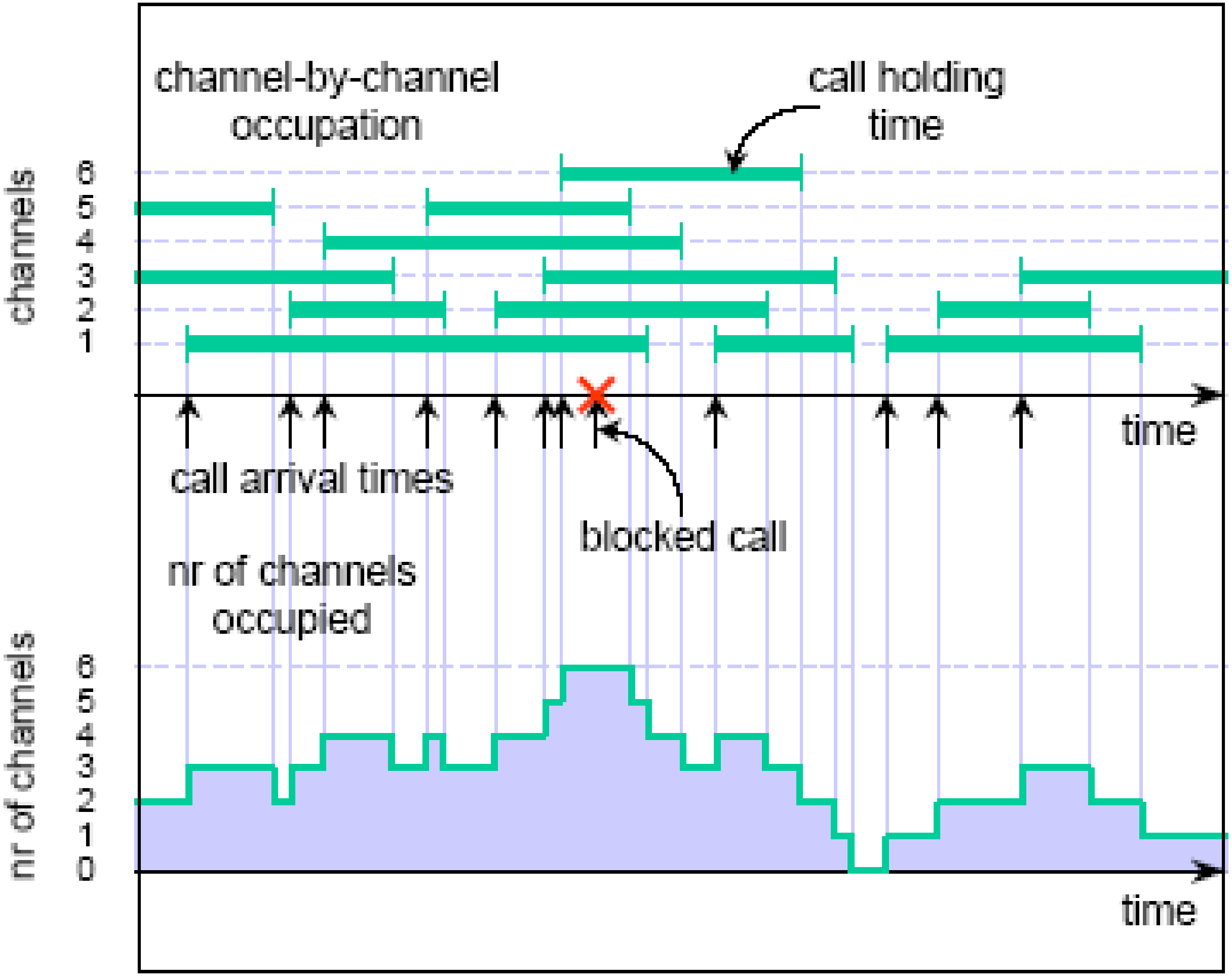


Fig. 4 System behavior ate the arriving traffic

Traffic process



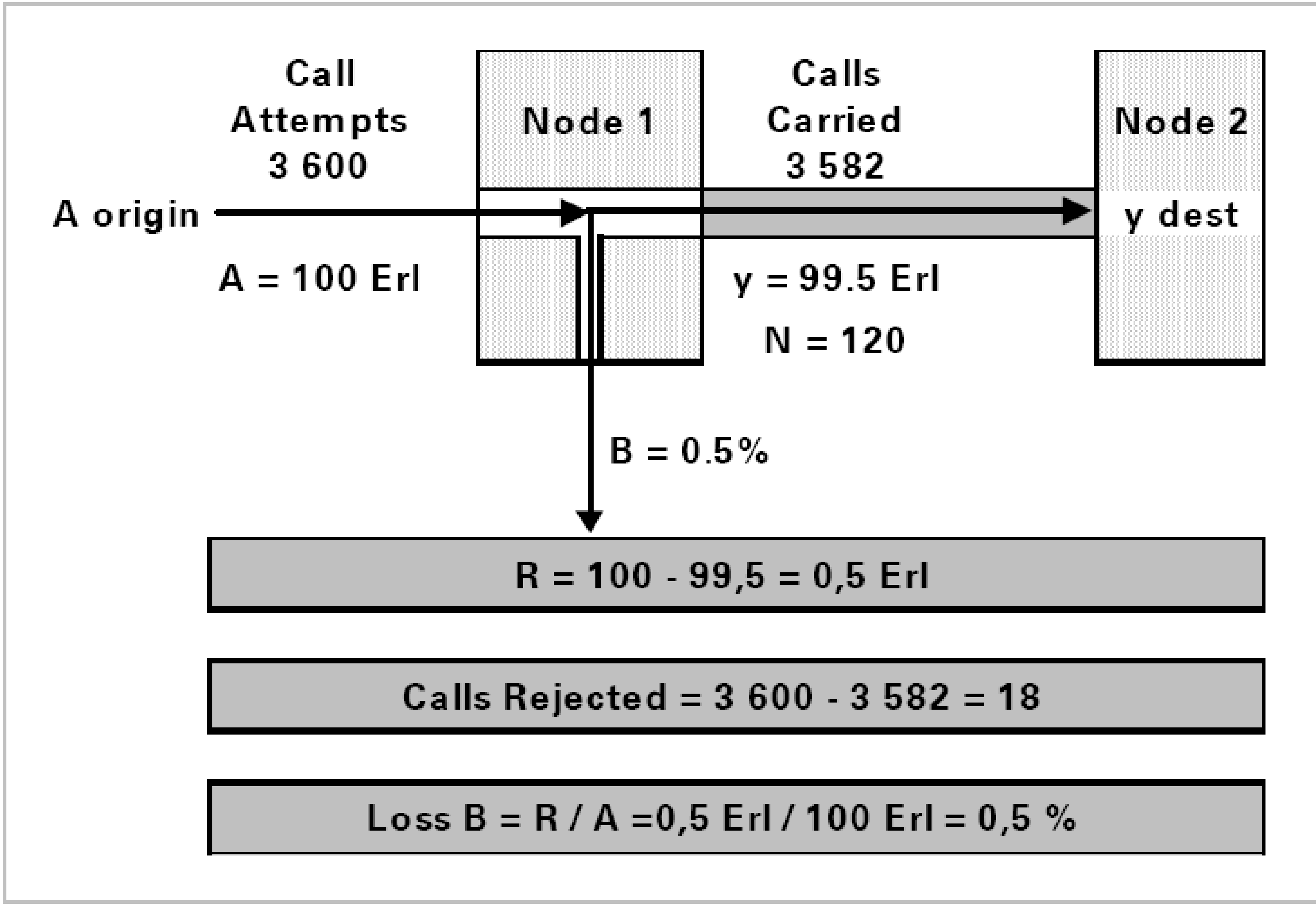


Fig. 17 Traffic variable calculation example

Examples of Cellular Traffic Volume

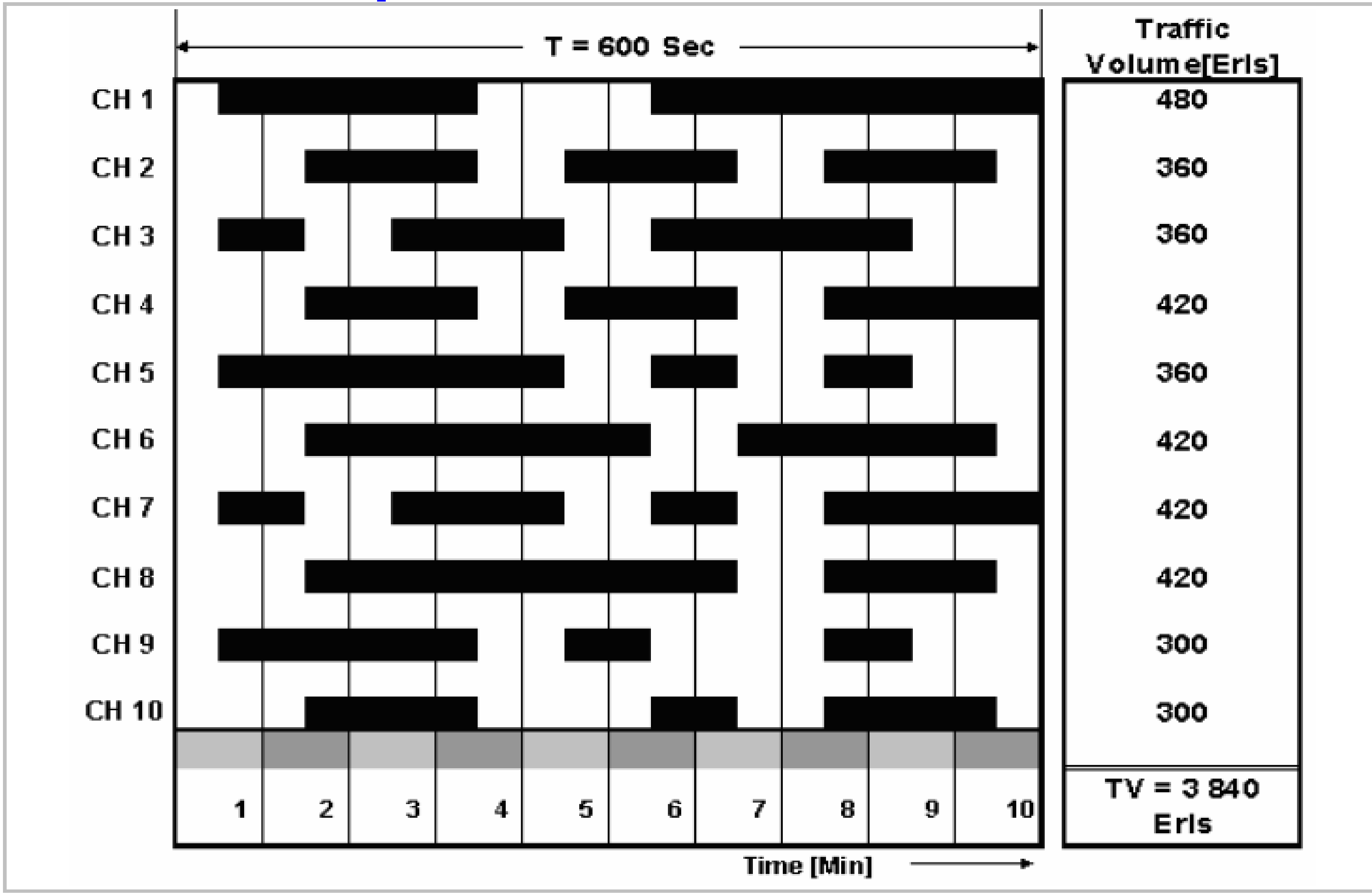


Fig. 8 Traffic Volume

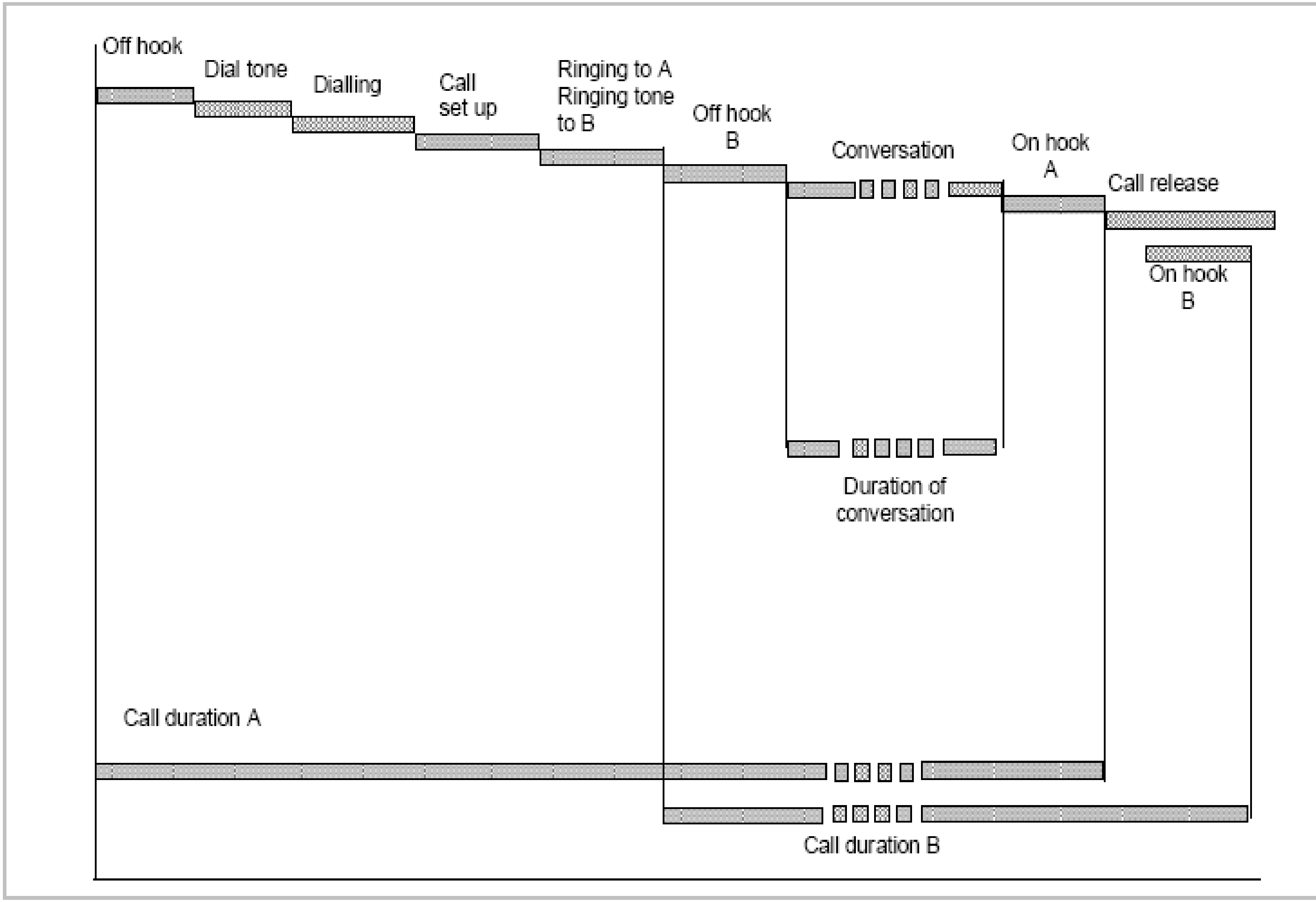


Fig. 7 Holding Time

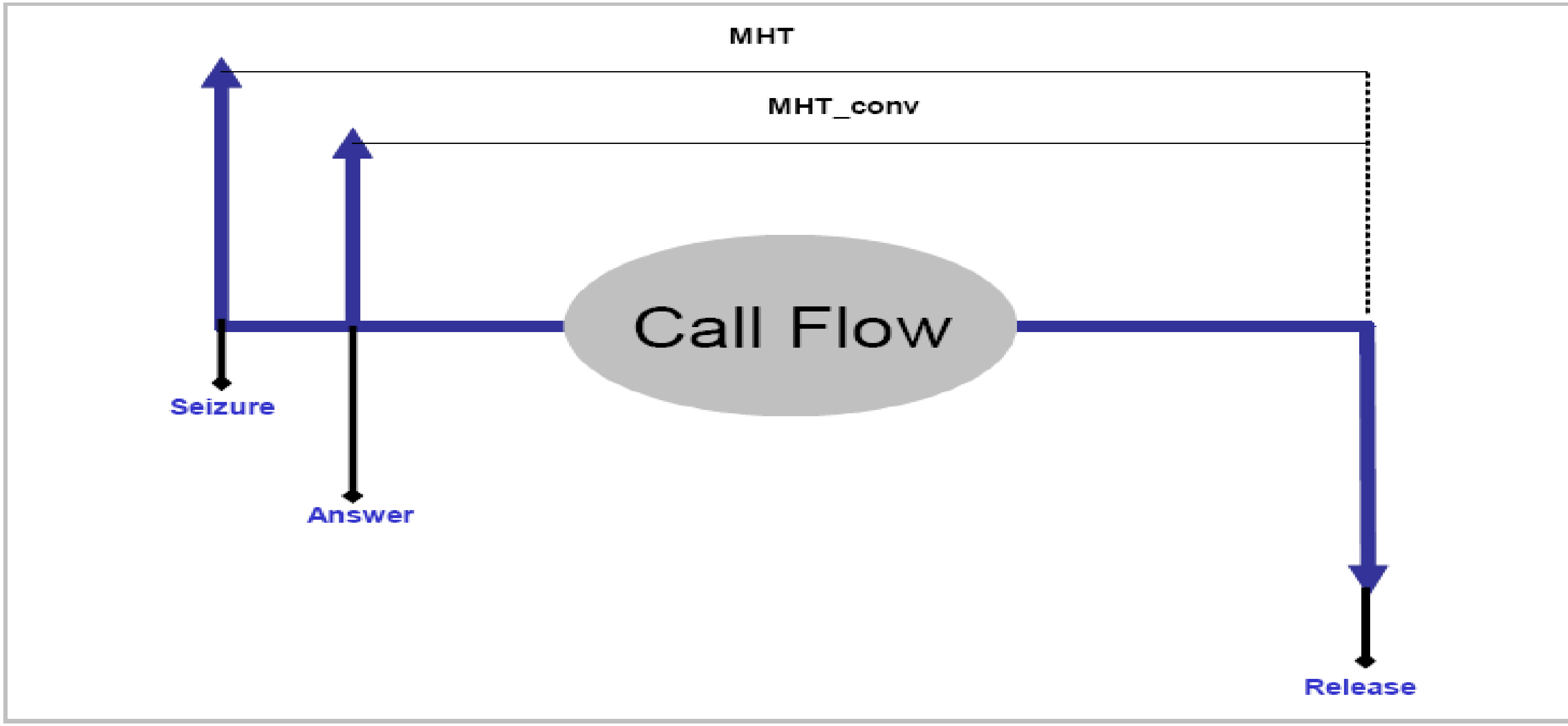


Fig. 9 Mean Holding Time

MHT [sec] = TV [Erl.s] / (N´Calls)

MHT_Conv [sec] = TV_Conv [Erl.s] / (N´Calls with Answer)

	Call 1	Call 2	Call 3	Call 4	Call 5	Call 6	Call 7	Call 8	Call 9	Call 10
Holding Time (sec)	3	120	100	130	2	4	80	1	200	24
Holding Time with Answer (sec)	-	116	95	127	-	-	77	-	195	-

Traffic Volume (TV) = t1 + t2 + ... + t10 = 664 sec

Traffic Volume with Answer (TV_Conv) = t_Conv1 + t_Conv2 + ... + t_Conv10 = 610 sec

Mean Holding Time = MHT = TV / N´Calls

MHT = 664 / 10 = 66.4 sec

Mean Holding Time with Answer = MHT_Conv = TV_Conv / N´Calls with Answer

MHT_Conv = 610 / 5 = 122 sec

Traffic load and cell size

- **Semakin banyak trafik dibangkitkan, semakin banyak diperlukan base station untuk melayani pelanggan. Jumlah dari base station sederhananya sama dengan jumlah sel,**
- **Bagaimana menambah jumlah pengguna yang dapat dilayani ?**
  - **cel splitting**
    - This simply works by dividing the cells already present into smaller sizes hence increasing the traffic capacity
  - **Sektorisasi**
    - The cost of equipment can also be cut down by reducing the number of base stations through setting up three neighbouring cells, with the cells serving three 120° sectors with different channel groups.

Trunking

- In a trunked radio system,
  - A large number of users share a small pool of channels in a cell on a per call basis
  - A channel is allocated on a per call basis,
  - On termination of call, the previously occupied channel is returned to the pool of available channels
  - When all channels are in use, access by a new user is blocked

Traffic Measurement Unites

- **Erlangs:**

  Traffic intensity (in honour of a Danish mathematician) is the average number of calls simultaneously in progress over a certain time.

  One Erlang is one channel occupied continuously for one hour.

  - In data communications, an 1 E = 64 kbps
  - In telephone, 1 Erlang = 1 x 3600 call seconds

- **% of Occupancy**
- **Peg count: The No. of attempts to use a piece of equipment**

Traffic Capacity

- How to compare the quality of services provides by different service providers?
- What is the probability of not being able to make a call?
- What is the probability of waiting before a call is connected?

All these can be explained by the Grade (Quality) of Service (GOS):

.

GOS

- Is a measure of the call blocking

or

- The ability to make call during the busiest time
- It 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

How to Estimate Traffic Intensity

The traffic intensity offered by each user is:

$$A_I = \mu H \qquad \text{Erlangs}$$

where

H is the average duration (holding time) of a call

μ is the average number of call requested/hour

If there are U users and an unspecified number of channels.

The total offered traffic intensity is:

$$A_T = U A_I \qquad \text{Erlangs}$$

How to Estimate Traffic Intensity - *contd.*

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

$$A_c = UA_I / C \qquad \text{Erlangs/channels}$$

The **offered traffic** (which is the volume of traffic offered to a switch), is defined as:

Offered load = carried load + overflow

The carried traffic is the actual traffic carried by a switch.

Traffic Intensity Models

Three traffic intensity model tables are used in practice

- Erlang B Formula (blocked calls cleared); can over estimate
  - Engset formula (probability of blocking in low density areas); used where Erlang B model fails
- Erlang C Formula (blocked calls delayed or held in queue indefinitely)
- Poisson Formula(blocked calls held in queue for a limited time only)
- Binomial Formula: (lost calls held)

Erlang B Model - Characteristics

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

- No waiting is allowed (lost calls are cleared)
- Traffic originated from an infinite numbers of sources
- Limited No. of trunk (or serving channels)
- Memory-less, channel requests at any time
- infinite number of channels in pool
- 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)

Probability of Blocking $p(B)$

Also known as the Erlang-B formula given by:

$$P(B) = \frac{\dfrac{A_I^{\,C}}{C!}}{\displaystyle\sum_{k=0}^{C} \frac{A_I^{\,k}}{k!}}$$

where

A_I is the traffic intensity offered by each user

Probability of Blocking $p(B)$ - *contd.*

The carried traffic is $A_{ca} = A_I\,[1 - p(B)]$

The efficiency of the channel usage is $\eta = \dfrac{A_{ca}}{C}$

* The start-up systems usually begins with a GOS of 0.02 (2% of the blocking probability) rising up to 0.5 as the system grows.
* If more subscribers are allowed in the system the blocking probability may reach unacceptable values.

Using the Erlang B Table

- Locate the column with the desired blockage level;
- While staying in the same column, find the row with the desired Erlang value (round off the Erlang value as necessary);
- Find the number of trunks in the selected row (at the intersection);

Efficiency Measures

1- Spectrum efficiency

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

$$\eta_{se} = \frac{\text{Traffif (Erlang)}}{\text{Bandwidth} \times \text{area}}$$

$$= \frac{\text{No. of channels/cell} \times \text{Offered traffic/channel}}{\text{Bandwidth} \times \text{area}} \qquad \left(\frac{Erlang}{kHz \cdot km^2}\right)$$

It depends on:

- Number of required channels per cell
- Cluster size of the interference group

Efficiency Measures

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.

Busy-Hour

- In telephony, it is customary to collect and analyze traffic in hourly blocks, and to track trends over months, quarters, and years
  - When making decisions about number of trunks required, we plan the trunks needed to support the busiest hour of a normal day
  - Special events (disasters, one-of-a-kind traffic tie-ups, etc.) are not considered in the analysis *(unless a marketing-sponsored event)*
- Which Hour should be used as the Busy-Hour?
  - Some planners choose one specific hour and use it every day
  - Some planners choose the busiest hour of each individual day ("floating busy hour")
  - Most common preference is to use "floating (bouncing)" busy hour determined individually for the total system and for each cell, but to exclude special events and disasters
  - In the example just presented, 4 PM was the busy hour every day

Trunking

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  - A channel is allocated on a per call basis,
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  - When all channels are in use, access by a new user is blocked

How Much Traffic will a Highway Produce ?

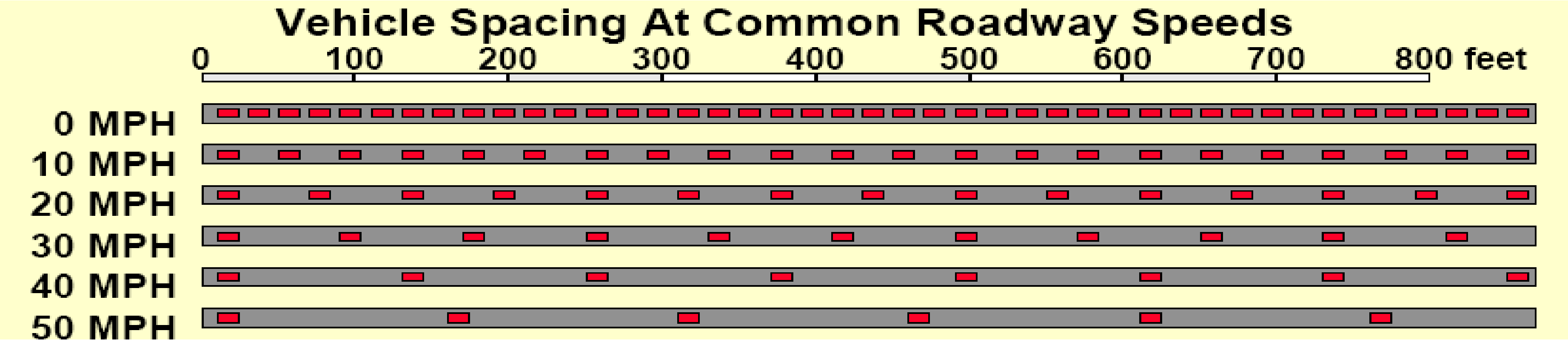
Traffic Density Along Roadways

Vehicles per mile

Vehicle Speed, MPH	Vehicle Spacing, feet	Vehicles per mile, per lane
0	20	264
10	42	126
20	64	83
30	86	61
45	119	44
60	152	35

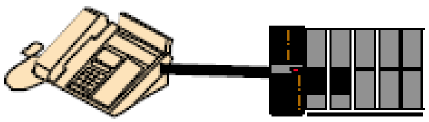
Vehicle spacing 20 ft. @stop
Running Headway 1.5 seconds

- Number of lanes and speed are the main variable determining number of vehicles on major highways
  - Typical headway ~1.5 seconds
  - Table and figure show capacity of 1 lane
- When traffic stops, users generally increase calling activity
- Multiply number of vehicles by percentage penetration of population to estimate number of subscriber vehicles



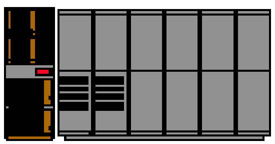
Dimensioning the System:
An Interactive, Iterative Process

- Some traffic engineering decisions trigger resource acquisition
  - additional blocks of numbers from the local exchange carrier
  - additional cards for various functions in the switch and peripherals
  - additional members in PSTN trunk groups; additional T-1/E-1s to busy sites
- Some traffic engineering decisions trigger more engineering
  - finding more frequencies to add to blocking sites
  - adding additional cells to relieve blocking
  - finding short-term fixes for unanticipated problems
- This course is concerned primarily with determining **the number of voice channels required in cells**, with the related site engineering and frequency or code planning

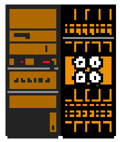


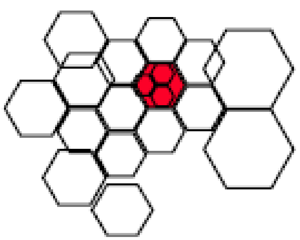
PSTN Office

DMS-MTX



Cell





Basics of Traffic Engineering
Terminology & Concept of a Trunk

- Traffic engineering in telephony is focused on the **voice paths which users occupy**. They are called by many different names:
  - **trunks**
  - **circuits**
  - **radios, transceivers ("TRXs"), channel elements (CDMA)**
- Some other common terms are:
  - **trunk group**
    - a trunk group is several trunks going to the same destination, combined and addressed in switch translations as a unit , for traffic routing purposes
  - **member**
    - one of the trunks in a trunk group

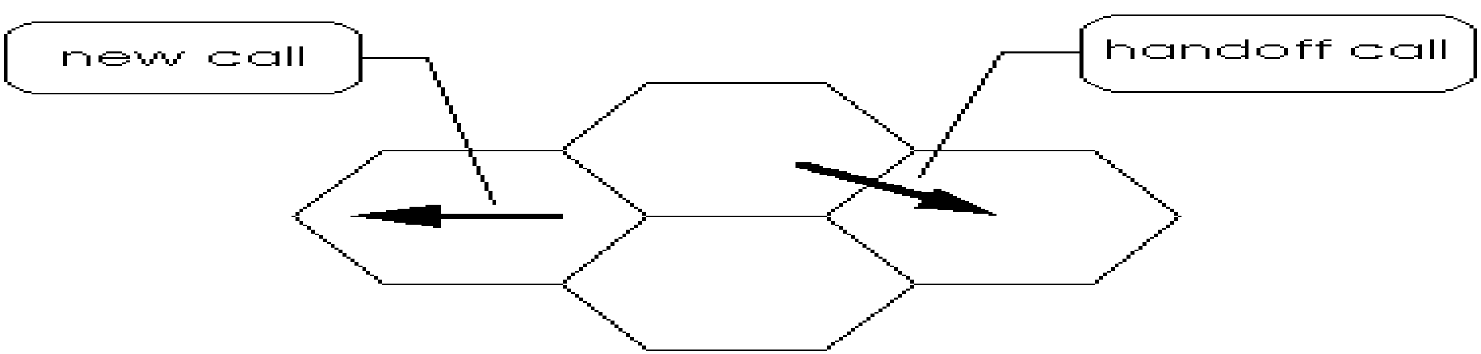
Cellular GoS

- In general, GoS is measured by looking at carried traffic, offered traffic and calculating the lost traffic. The proportion of lost calls is the measure of GoS. For cellular circuit groups an acceptable GoS is 0.02. This means that two users of the circuit group out of hundred will encounter a call refusal during the busy hour at the end of the planning period. The grade of service standard is thus the acceptable level of traffic that the network can lose.
- GoS is calculated from the /Erlang_unit#Erlang_B_formula, as a function of the number of channels required for the offered traffic intensity.

- Mobile radio networks have traffic issues that do not arise in connection with the fixed line PSTN. It must be noted that a mobile handset which is moving in a cell will record a signal strength that varies. This signal strength is subject to quick fading and interference with other signals resulting in a poor carrier to interference (C/I) ratio. A high C/I ratio yields quality communication. A good C/I ratio is achieved in cellular systems by using lowest power levels possible.

In cellular networks, blocking occurs when a base station has no free channel to allocate to a mobile user. One distinguishes between two kinds of blocking:blocking of new calls, and blocking of ongoing calls due to the mobility of the users (handoff blocking).

It's important to study the factors that affect the probabilities of these two kind of blocking, because the Quality of Service in cellular networks is mainly determined by them.



Traffic Load and Cell Size

- More and more traffic generated, the more base stations needed to serve customers. The number of base stations is simply equal to the number of cells,

- How to increase the number of users that can be served?
- **cel splitting**
  - This simply works by dividing the cells already present into smaller sizes hence increasing the traffic capacity
- **Sektorisasi**
  - The cost of equipment can also be cut down by reducing the number of base stations through setting up three neighbouring cells, with the cells serving three 120° sectors with different channel groups.

Spectral efficiency and sectorization

- Mobile radio networks are operated with finite, limited resources (the spectrum of frequencies available) and these resources have to be used effectively to ensure that all users receive service, that is quality of service is maintained. The need to carefully use the limited spectrum brought about the development of cells in mobile networks. Systems that efficiently use the available spectrum have been developed e.g. the GSM system. Walke defines spectral efficiency as the traffic capacity unit divided by the product of bandwidth and surface area element, and is dependent on the number of radio channels per cell and the cluster size (number of cells in a group of cells), where Nc is the number of channels per cell, Bs is the system bandwidth, and Ac is Area of cell.

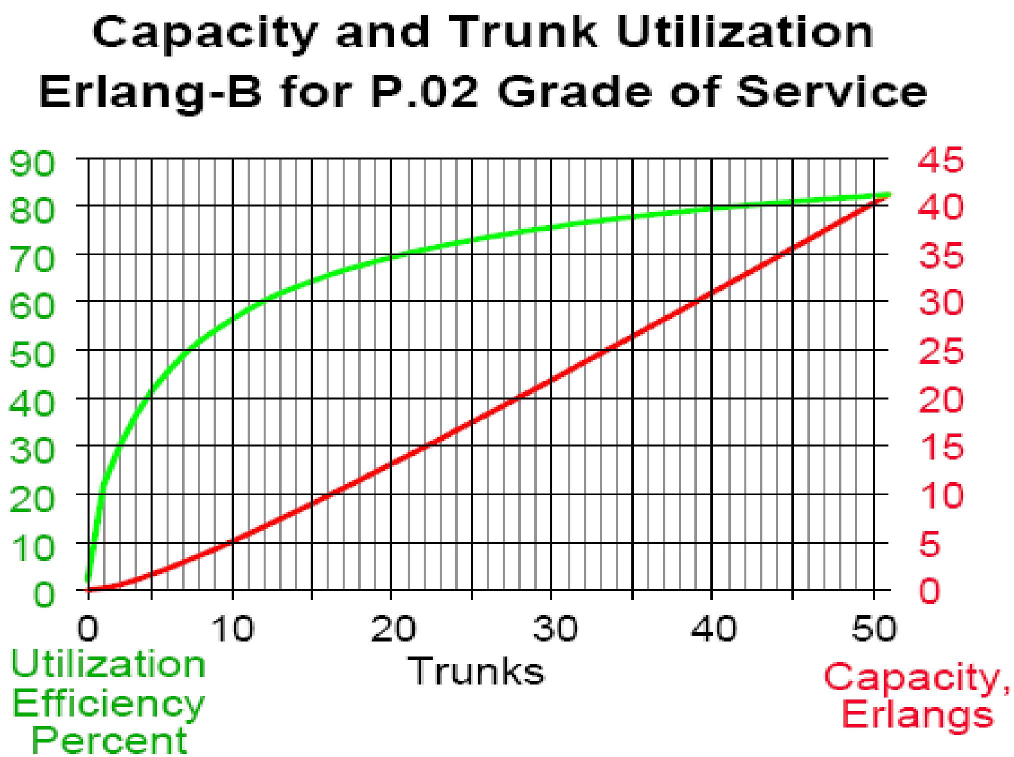
Sectorization

- Sectorization is briefly described in **traffic load and cell size** as a way to cut down equipment costs in a cellular network. When applied to clusters of cells sectorization also reduces co-channel interference, according to Walke. This is because the power radiated backward from a directional base station antenna is minimal and interfering with adjacent cells is reduced. (The number of channels is directly proportional to the number of cells.) The maximum traffic capacity of sectored antennas (directional) is greater than that of omnidirectional antennas by a factor which is the number of sectors per cell (or cell cluster).

Traffic capacity versus coverage

- Cellular systems use one or more of four different techniques of access (TDMA, FDMA, CDMA, SDMA). See Cellular concepts. Let a case of Code Division Multiple Access be considered for the relationship between traffic capacity and coverage (area covered by cells). CDMA cellular systems can allow an increase in traffic capacity at the expense of the quality of service.
- In TDMA/FDMA cellular radio systems, Fixed Channel Allocation (FCA) is used to allocate channels to customers. In FCA the number of channels in the cell remains constant irrespective of the number of customers in that cell. This results in traffic congestion and some calls being lost when traffic gets heavy.
- A better way of channel allocation in cellular systems is Dynamic Channel Allocation (DCA) which is supported by the GSM, DCS and other systems. DCA is a better way not only for handling bursty cell traffic but also in efficiently utilising the cellular radio resources. DCA allows the number of channels in a cell to vary with the traffic load, hence increasing channel capacity with little costs. Since a cell is allocated a group of frequency carries for each user, this range of frequencies is the bandwidth of that cell, BW. If that cell covers an area Ac, and each user has bandwidth B then the number of channels will be BW/B. The density of channels will be. This formula shows that as the coverage area Ac is increased, the channel density decreases.

Number of Trunks, Capacity, and Utilization Efficiency

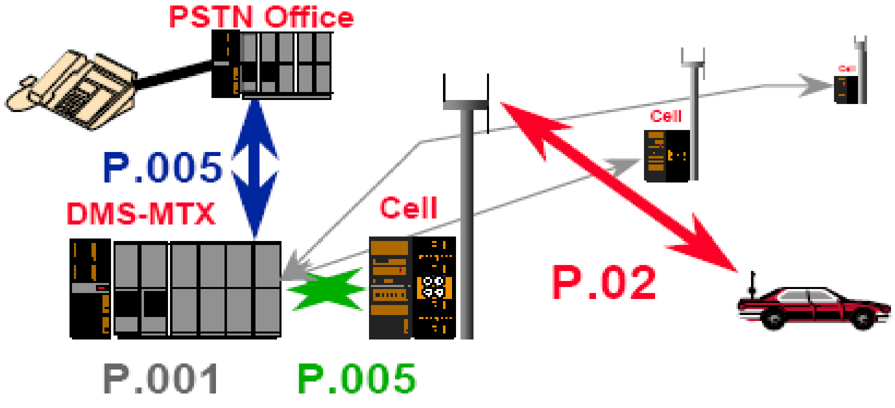


- The graph at left illustrates the capacity in Erlangs of a given number of trunks, as well as the achievable utilization efficiency
- For accurate work, tables of traffic data are available
  - Capacity, Erlangs
  - Blocking Probability (GOS)
  - Number of Trunks
- Notice how capacity and utilization behave for the numbers of trunks in typical cell sites

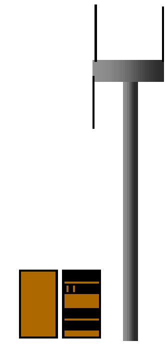
Principles of Traffic Engineering
Blocking Probability / Grade of Service

- 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



Number of Trunks 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%!

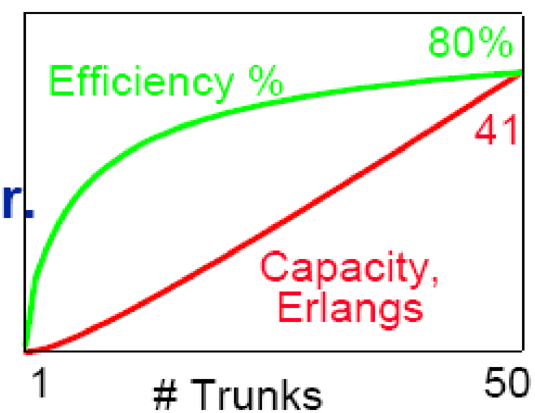
- Adding just one trunk relieves things greatly. Now we can use trunk 1 heavily, with trunk 2 handling the overflow. Efficiency rises to 11%

Erlang-B P.02 GOS

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

The Principle of Trunking Efficiency

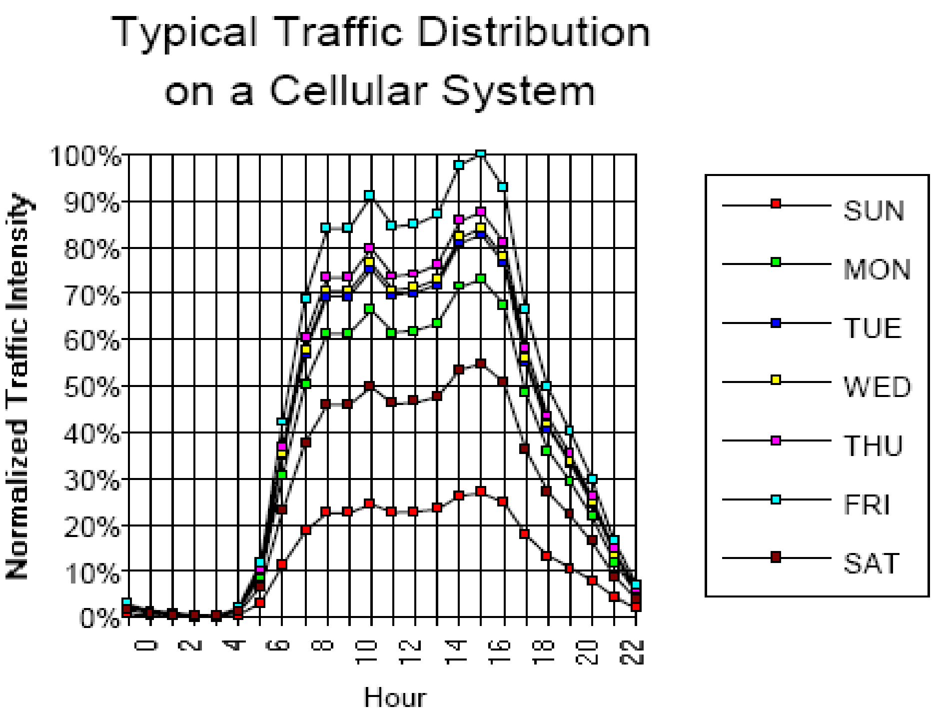
- **For a given grade of service, trunk utilization efficiency increases as the number of trunks in the pool grows larger.**
  - For trunk groups of several hundred, utilization approaches 100%.



Channel Holding Time

Important parameters like the carrier to interference (C/I) ratio, spectral efficiency and reuse distance determine the quality of service of a cellular network. Channel Holding Time is another parameter that can affect the quality of service in a cellular network, hence it is considered when planning the network. It must be mentioned that it is not an easy task to calculate the channel holding time. (This is the time a Mobile Station (MS) remains in the same cell during a call). Channel holding time is therefore less than call holding time if the MS travels more than one cell as handover will take place and the MS relinquishes the channel. Practically, it is not possible to determine exactly the channel holding time. As a result, different models exists for modelling the channel holding time distribution. In industry, a good approximation of the channel holding time is usually sufficient to determine the network traffic capability. One of the papers in Key and Smith defines channel holding time as being equal to the average holding time divided by the average number of handovers per call plus one. Usually an exponential model is preferred to calculate the channel holding time for simplicity in simulations. This model gives the distribution function of channel holding time and it is an approximation that can be used to obtain estimates channel holding time. The exponential model may not be correctly modelling the channel holding time distribution as other papers may try to prove, but it gives an approximation. Channel holding time is not easily determined explicitly, call holding time and user's movements have to be determined in order to implicitly give channel holding time. The mobility of the user and the cell shape and size cause the channel holding time to have a different distribution function to that of call duration (call holding time). This difference is large for highly mobile users and small cell sizes. Since the channel holding time and call duration relationships are affected by mobility and cell size, for a stationary MS and large cell sizes, channel holding time and call duration are the same.

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.

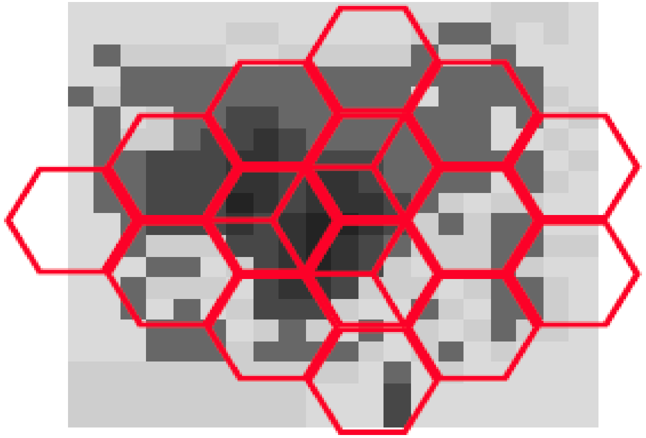
- Peak traffic on cellular systems is usually daytime business-related traffic; on PCS systems, evening traffic becomes much more important and may actually contain the system busy hour
- Evening taper is more gradual than morning rise
- Wireless systems for PCS and LEC-displacement have peaks of residential 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**

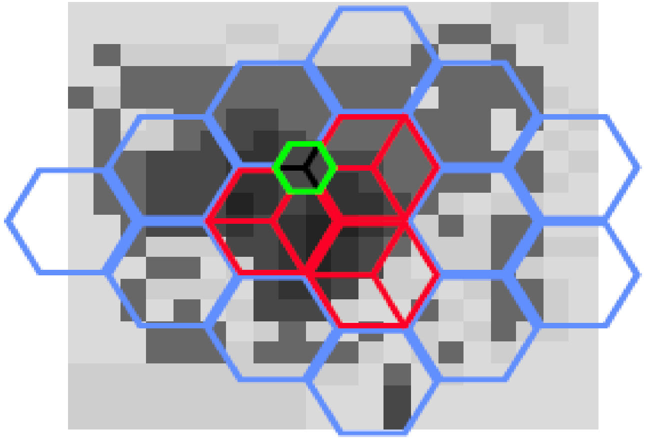
Profile of Typical Cellular Usage

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

How Much Will a New Cell Absorbs ?

Determining Number of Trunks required for a new Growth Cell





When new growth cells are added, they absorb some of the traffic formerly carried by surrounding cells

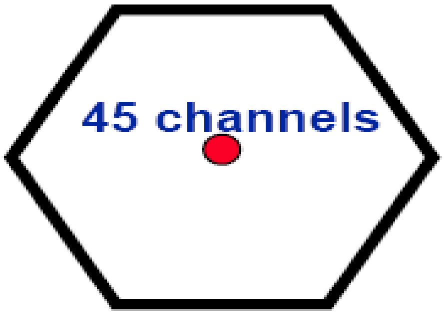
- Two approaches to estimating traffic on the new cell and on its older neighbors:
  - **if blocking was not too severe**, you can estimate redistributed traffic in the area based on the new division of coverage
  - **if blocking is severe**, (often the case), users will stop trying to call in locations where they've learned to expect blocking. ***Users are programmable!!***
    - reapply basic traffic assumptions in the area, like engineering new system, for every nearby cell
    - watch out! overall traffic in the area may increase to fill the additional capacity and the new cell itself may block as soon as it goes in service

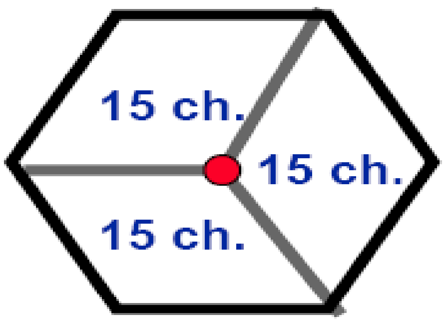
Dimensioning
System Administrative Functions

System administrative functions also require traffic engineering input. While these functions are not necessarily performed by the RF engineer, they require RF awareness and understanding.

- **Paging**
  - The paging channel has a definite capacity which must not be exceeded. When occupancy approaches this limit, the system must be divided into zones, and zone paging implemented.
- **Autonomous Registration**
  - Autonomous registration involves numerous parameters and the registration attempts must be monitored and controlled to avoid overloading.
- **Locate Measurements**
  - Locate measurement requests can overrun the capacity of locate receivers in specific cells. This must be monitored in busy systems and controlled by careful attention to cell-pair definitions and trigger thresholds. Course 1001, Handoff Seminar, provides more details.

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**

Grade of service

Introduction

- In telecommunication, the quality of voice service is specified by two measures: The **GOS (grade of service)** and the **QoS (quality of service)**.
- **Grade of service** is the probability of a call in a circuit *group* being blocked or delayed for more than a specified interval, expressed as a vulgar fraction or decimal fraction. This is always with reference to the busy hour when the traffic intensity is the greatest. Grade of service may be viewed independently from the perspective of incoming versus outgoing calls, and is not necessarily equal in each direction or between different source-destination pairs.
- On the other hand, the **Quality of service** which a *single* circuit is designed or conditioned to provide, e.g. voice grade or program grade is called the quality of service. Criteria for different qualities of service may include equalization for amplitude over a specified band of frequencies, or in the case of digital data transported via analogue circuits, or include equalization for phase also.

What is Grade of Service and how is it measured?

- When a user attempts to make a telephone call, the routing equipment handling the call has to determine whether to accept the call, reroute the call to alternative equipment, or reject the call entirely. Rejected calls occur as a result of heavy traffic loads (congestion) on the system and can result in the call either being delayed or lost. If a call is delayed, the user simply has to wait for the traffic to decrease, however if a call is lost then it is removed from the system.
- The Grade of Service is one aspect of the quality a customer can expect to experience when making a telephone call . In a Loss System, the Grade of Service is described as that proportion of calls that are lost due to congestion in the busy hour . For a Lost Call system, the Grade of Service can be measured.

- For a delayed call system, the Grade of Service is measured using three separate terms :
- The mean delay *td* – Describes the average time a user spends waiting for a connection if their call is delayed.
- The mean delay *to* – Describes the average time a user spends waiting for a connection whether or not their call is delayed.
- The probability that a user may be delayed longer than time *t* while waiting for a connection. Time *t* is chosen by the telecommunications service provider so that they can measure whether their services conform to a set Grade of Service.

Calculating the Grade of Service

- To determine the Grade of Service of a network when the traffic load and number of circuits are known, telecommunications network operators make use of *Equation 2*, which is the Erlang-B equation

- *A* = Expected traffic intensity in Erlangs, *N* = Number of circuits in group
- This equation allows operators to determine whether each of their circuit groups meet the required Grade of Service, simply by monitoring the reference traffic intensity.
- (For delay networks, the Erlang-C formula allows network operators to determine the probability of delay depending on peak traffic and the number of circuits .)

What is Quality of Service?

- Quality of service is a measure of the **reliability** and **usability** of the telecommunications network . Mobile cellular companies have to offer a quality service to customers just as the fixed line PSTN companies have to. The quality is called QoS (quality of service). Part of Qos is grade of service or GoS.

Factors affecting QoS

- Many factors affect the quality of service of the network. It is common to only look at QoS from the customer's point of view, that is, QoS as judged by the user. There are standard metrics of QoS to the user that can be measured to judge the QoS. These indicators are: the **coverage**, **accessibility** (includes GoS), and the **audio quality**. In **coverage** the strength of the signal is measured using test equipment and this can be used to estimate the size of the cell. **Accessibility** is about determining the ability of the network to handle successful calls from mobile-fixed networks and from mobile-mobile networks. The **audio quality** considers monitoring a successful call for a period of time for the clarity of the communication channel. All these indicators are used by the telecommunications industry to judge the quality of service of the network

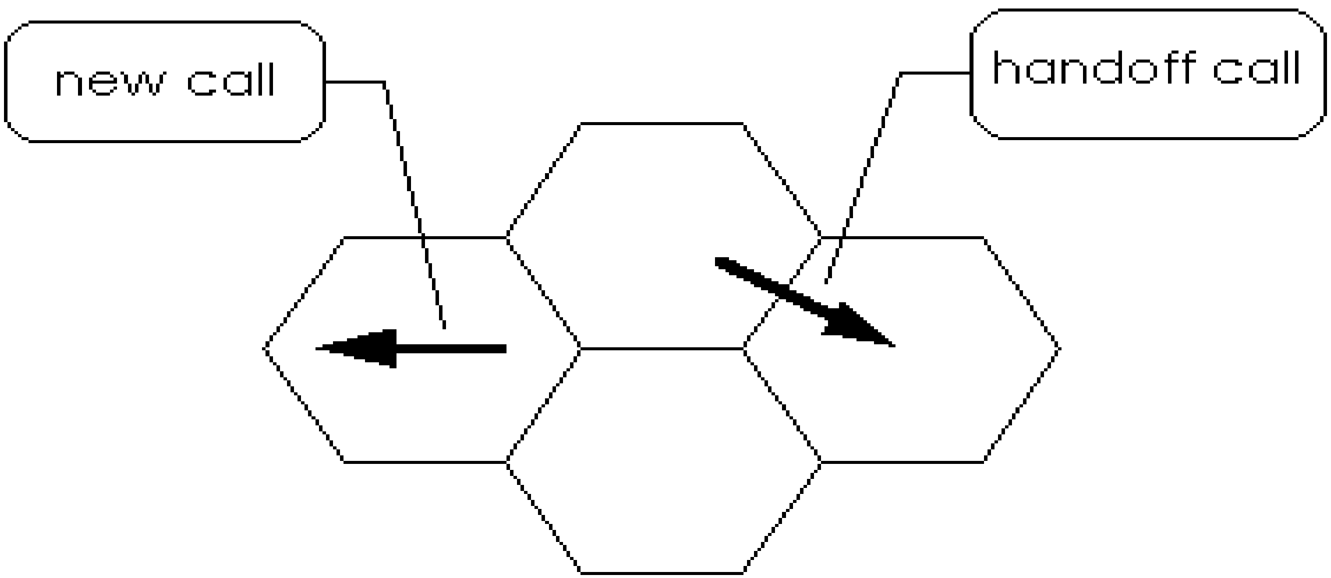
Measurement of QoS

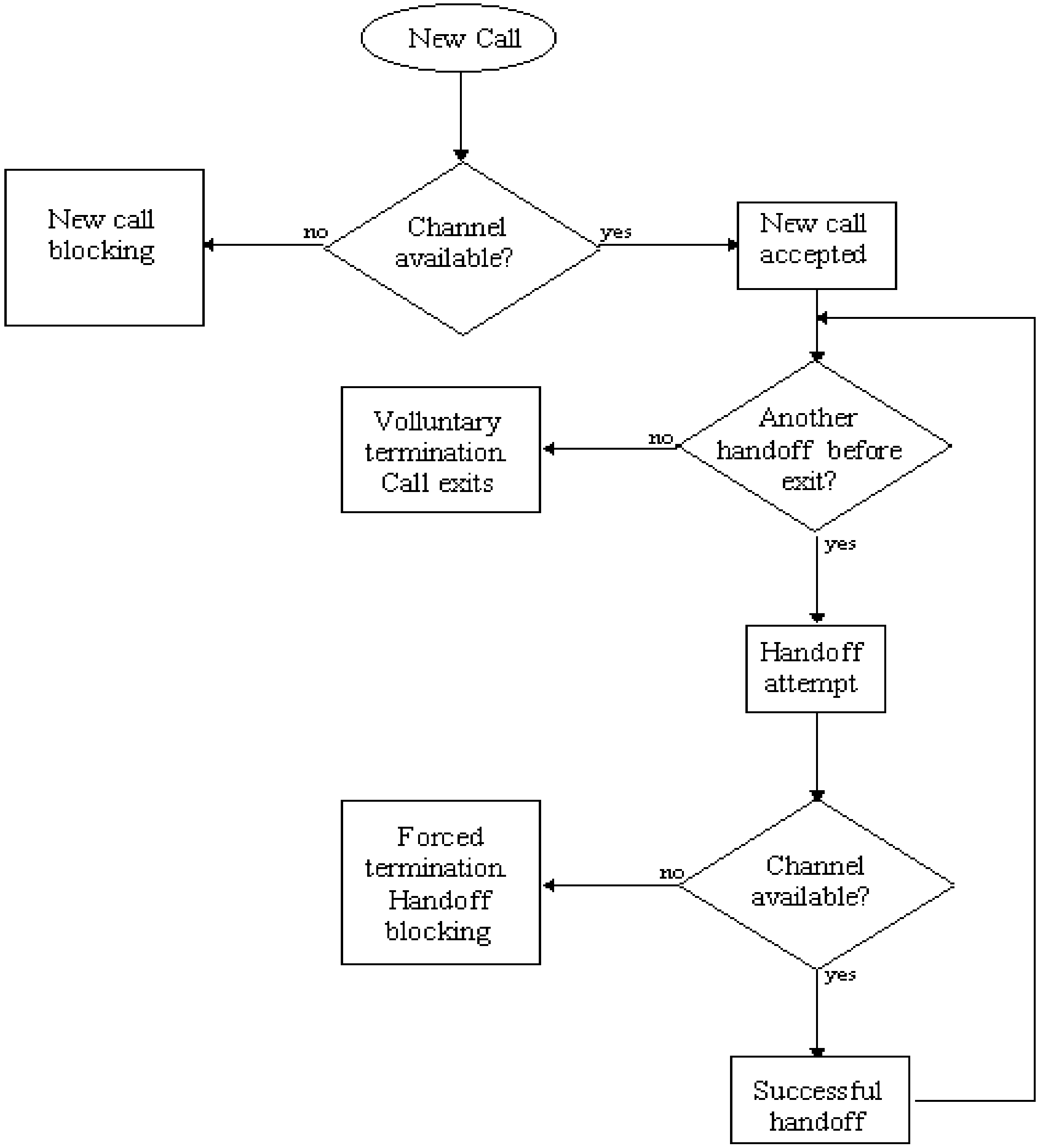
- The QoS in industry is also measured from the perspective of an expert (e.g. teletraffic engineer). This involves assessing the network to see if it delivers the quality that the network planner requires. Certain tools and methods (**protocol analysers, drive tests** and operations and maintenance **measurements**), are used for this QoS measurement :
- Protocol analysers are connected to BTSs, BSCs, and MSCs for a period of time to check for problems in the cellular network. When a problem is discovered the staff can record it and it can be analysed.
- Drive tests allow the network to be tested through the use of a team of people who take the role of users and take the QoS measures discussed above to judge the QoS of the network. This test does not apply to the entire network, so it is always a statistical sample.
- In the Operations and Maintenance Centres (OMCs), counters are used in the network for different events which provide the network operator with information on the state and quality of the network .
- Finally, **customer complaints** are a vital source of feedback on the QoS, and must not be ignored

Cellular GoS

- In general, GoS is measured by looking at **carried traffic, offered traffic and calculating the lost traffic.** The proportion of lost calls is the measure of GoS. For cellular circuit groups an acceptable GoS is 0.02. This means that two users of the circuit group out of hundred will encounter a call refusal during the busy hour at the end of the planning period. The grade of service standard is thus the acceptable level of traffic that the network can lose. GoS is calculated from the /Erlang_unit#Erlang_B_formula, as a function of the number of channels required for the offered traffic intensity.

In cellular networks, blocking occurs when a base station has **no free channel to allocate to a mobile user**. One distinguishes between two kinds of blocking: **blocking of new calls**, and **blocking of ongoing calls** due to the mobility of the users (**handoff blocking**). It's important to study the factors that affect the probabilities of these two kind of blocking, because the Quality of Service in cellular networks is mainly determined by them.





Model's properties:

Each cell has N channels.

In each cell, new calls are generated according to an independent Poisson process.

If termination is not forced, call holding time is Exponentially distributed. 70

One dimensional topology.

Homogeneous traffic.

Variable factors:

Parameters: - Number of cells - Number of channels in each cell - Load - User velocity

User mobility: memoryless, directional, markovian

Network topology: ring, line

Channel allocation policy: static, dynamic (channel borrowing)