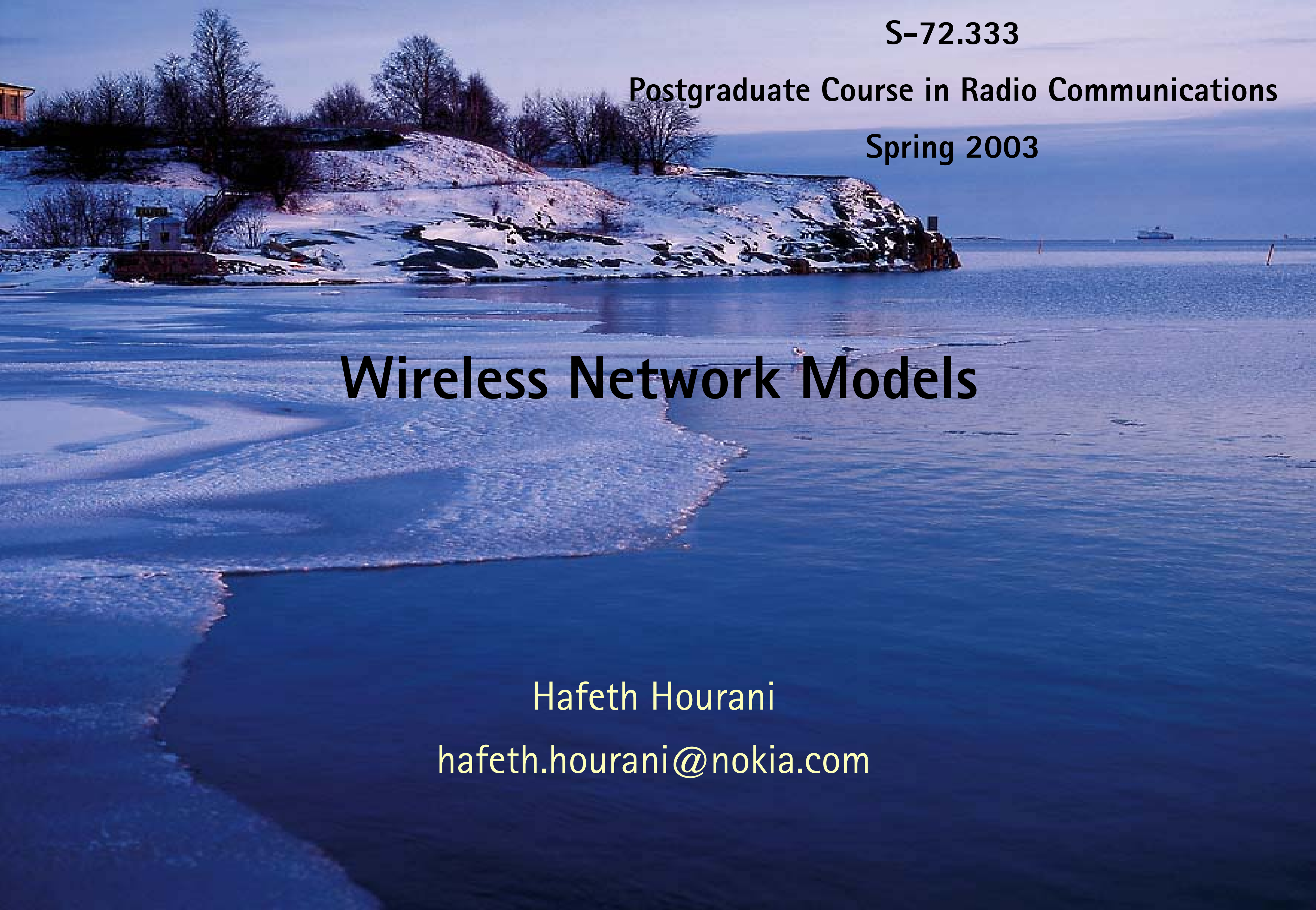

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Postgraduate Course in Radio Communications

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Wireless Network Models

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Contents

Background

- Resource Management Problem
  - Operator Perspective
    - Operator: needs maximum number of customers
      - Maximum number of users = Capacity of the system
  - Consumer Perspective
    - User: needs best Quality of Service (QoS)
- Capacity is a function of QoS requirements
    - Services requiring more resources per user limits the capacity of the system
- Resource Management Problem:
  - "***Design systems where the number of users is maximized for a given QoS requirement***"

Problem Aspects

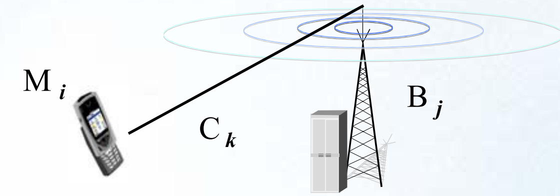
- The wireless network design problem
  - Design the fixed network infrastructure
    - How many base stations ?
    - Where to place them ?
    - What fixed network capacity has to be provided for different base stations ?

- The radio resource allocation problem
  - Given an infrastructure design.
    - How should the wireless resources be allocated to meet the instantaneous demand of the users and mobile terminals moving around in the network ?

Definitions

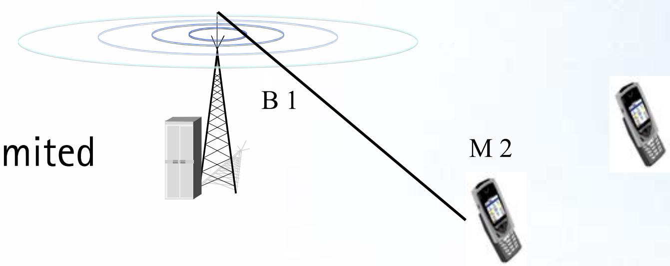
- Active mobile terminals
  - A mobile requiring a connection is an **active mobile terminal**

    ⇨ $\mathbf{M} = \{1, 2, \ldots, M\}$
  - M is a stochastic variable
    - Its distribution depends on traffic call intensity, duration of user session and the system behavior
    - Terminals become active independently
      - » Two Dimensional Poisson Point Process
      - » They are not completely dependent, since they are using the same set of channels
      - » Process rate ω (active terminals/ area unit)



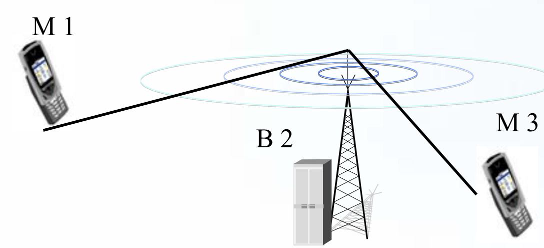
- Radio Access Ports (base stations)
  - The mobile terminal is served by access port. The number is limited

    ⇨ $\mathbf{B} = \{1, 2, \ldots, B\}$



- System Channels (waveforms)
  - System channels are numbered from the following set

    ⇨ $\mathbf{C} = \{1, 2, \ldots, C\}$
  - These channels are available for establishing links between access ports and terminals

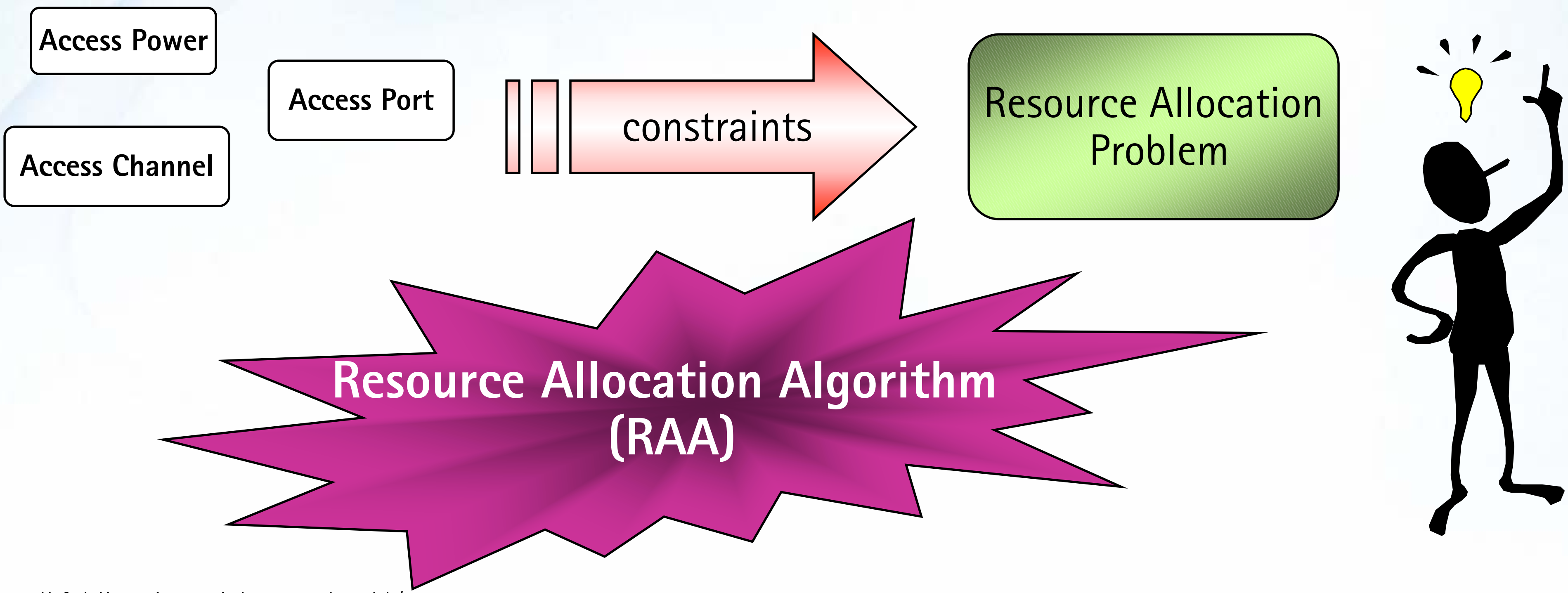


Radio Link Establishment

- To establish radio links, each terminal has to assign
  - An access port (base station) from set **B**
  - A channel from set **C**
  - A transmitter power for the access port and the terminal

Radio Link Constraints

- Limited number of access channels (**C**)
- Limited number of access ports (**B**)
- Constrained power assignment
- Interference caused by the access ports and terminals

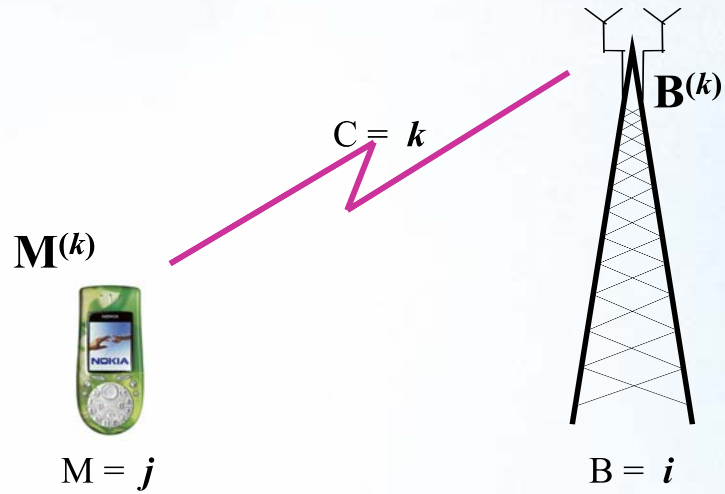


Notations

- $M^{(k)} = \{\, j$: terminal j has been assigned channel $k\}$, $k = 0,1,2,\ \ ,C$
- $B^{(k)} = \{i$: RAP i has been assigned channel $k\}$, $k = 0,1,2,\ \ ,C$

$$\bigcup_{k=0}^{C} M^{k} = M$$

$$\bigcup_{k=0}^{C} B^{k} = B$$



- The sets $M^{(k)}$ are usually disjoint
  - Each terminal uses only one channel at a time
- The sets $B^{(k)}$ are joint
  - RAP may serve multiple terminals using different channels

Propagation Constraints

- Link Gain
  - Between transmitters and receivers
  - $\mathbf{G}_{ij}$ is the power gain of the channel between port j and terminal i
- The received power in the receiver j, $\mathbf{P}_{rx,j}$ can be written as
  $P_{rx,j} = P_{tx,i}\, G_{ij}$
  Where $P_{tx,j}$ is the transmitter power at transmitter j.
- The link gain matrix

$$G = \begin{bmatrix} G_{11} & G_{12} & G_{1M} \\ G_{21} & G_{22} & G_{2M} \\ & & \\ G_{B1} & G_{B2} & G_{BM} \end{bmatrix}$$

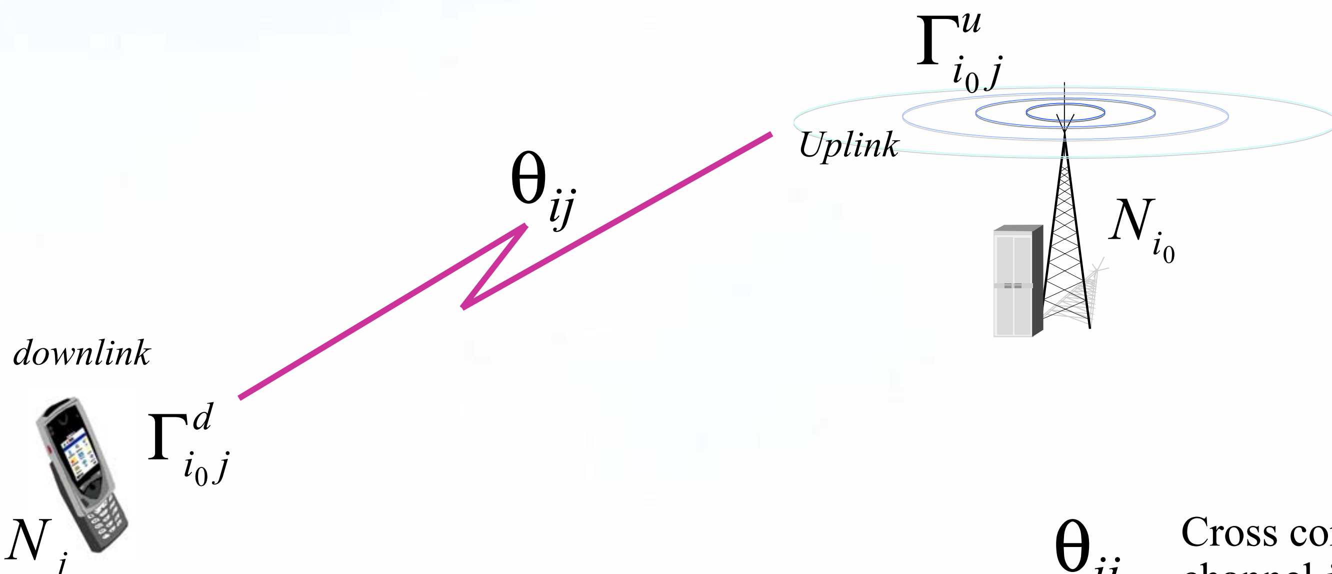
- This matrix describes the instantaneous propagation conditions in the system
- $\mathbf{G}_{ij}$'s are assumed to be random variables

Interference Constraints

- SIR
  - Signal to *interference* + *noise* ratio
  - Assuming only one channel in the system

$$\Gamma^{u}_{i_0 j} = \frac{P_j G_{i_0 j}}{\sum_{m \neq j} P_m \theta_{0,m} G_{i_0 m} + N_{i_0}} \geq \gamma^{u}_{j}$$

$$\Gamma^{d}_{i_0 j} = \frac{P_j G_{i_0 j}}{\sum_{b \neq j} P_b \theta_{0,b} G_{i_0 b} + N_j} \geq \gamma^{d}_{j}$$



θ_{ij} Cross correlation between channel ***i*** and ***j***

Interference (2)

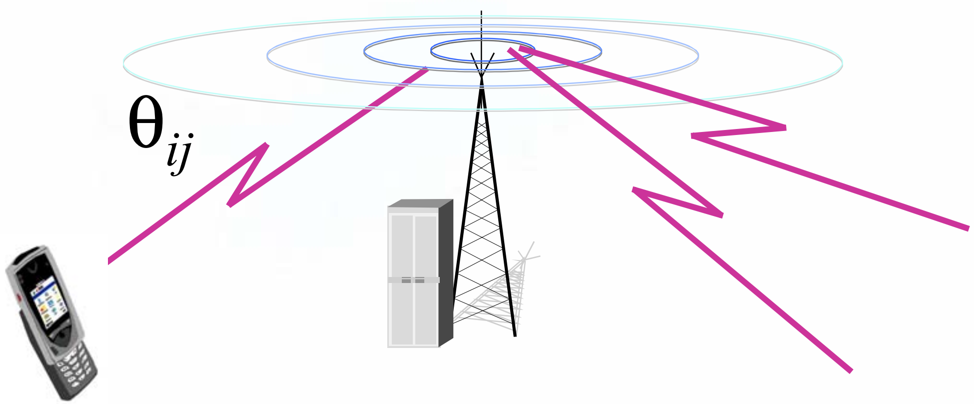
- Using orthogonal channels
    - **C** consists of orthogonal channels

$$\theta_{ij} = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases}$$

- The interference from other channels can be neglected given that the channels are orthogonal
    - Interference summations are taken over all the terminals using the same channel c only

$$\Gamma^{u}_{i_0 j} = \frac{P_j G_{i_0 j}}{\sum\limits_{\substack{m \neq j \\ m \in M^{(c)}}} P_m \theta_{0,m} G_{i_0 m} + N_{i_0}} \geq \gamma^{u}_{j}$$

$$\Gamma^{d}_{i_0 j} = \frac{P_j G_{i_0 j}}{\sum\limits_{\substack{b \neq j \\ b \in B^{(c)}}} P_b \theta_{0,b} G_{i_0 b} + N_{j}} \geq \gamma^{d}_{j}$$



System Capacity

- System Capacity = Largest number that can be handled
  - It might not be possible to satisfy the requirements for all M terminals
- Measuring System Capacity
  - Definition: Y = channels available at a given instant of time
    - **Y** is the number of available channels in the system at given instant of time
      - » Random Variable
    - **C** is the total number of channels in the system
      - » Constant
  - Definition: Z = failed assignment
    - Terminals that cannot be assigned at a given instant of time because of unavailability of free system channels
    - Z = M - Y
- Assignment Failure Rate ν

$$\nu = \frac{E(Z)}{E(M)} = \frac{E(Z)}{\omega A}$$

where **ω** = active terminals / area unit (**traffic load**)

A = Cell Area

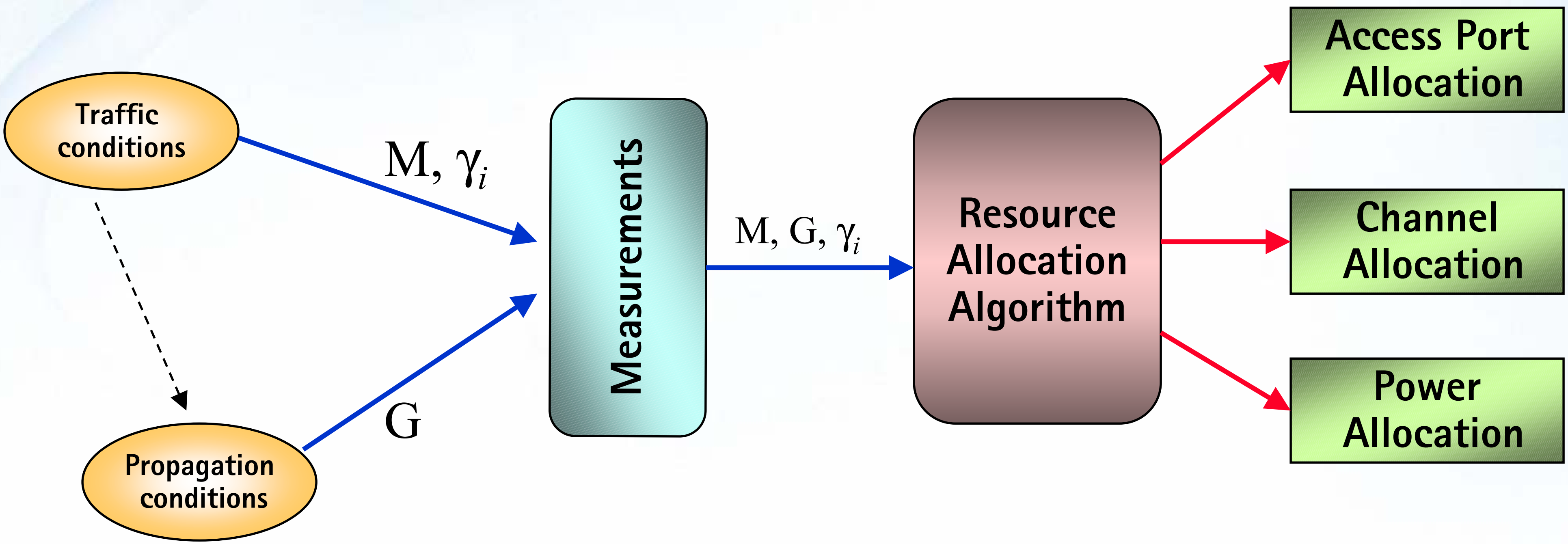
Instantaneous Capacity

- For large ωA
  - The assignment failure rate (ν) $\cong$ the probability that it is not possible to provide a combination of channel and access port to some randomly chosen terminals at some given instant of time without violating the interference constraints

- Definition
  - Threshold failure rate ν_0
  - Instantaneous Capacity ⇨ $\omega_*(\nu_0) = \{ \max \omega : \nu \leq \nu_0 \}$
    - The maximum allowed traffic load in order to keep the assignment failure rate below a threshold ν_0

RAA Design

- User behavior model
  - Users can request many services characterized by various sets of QoS parameters like
    - Bit Rate, Error Probabilities, Delays
- QoS model
- Snapshot Analysis



Dynamic & Static RAA

- Dynamic RAA
  - Adapts to
    - Propagation conditions change (mobile terminals)
    - Traffic conditions change
  - Problems
    - Constant recalculation and updating further complicates the resource assignment problem
    - Measurements not always reliable
  - Example
    - Use measured SIR to predict future SIR
  - Practicality
    - Needs to track changes in propagation conditions and user traffic
- Static RAA
  - Based on priori knowledge (done at planning stage)
    - Average propagation conditions in certain areas
    - Average traffic load conditions
    - Given QoS requirements

QoS Model and User Behavior

3G (UMTS) Bearer Service Classes

Service Class	Typical Applications	Service Functional Characteristics
Conversational (Real Time)	Voice	• Preserve time relations between entities • Stringent preservation of conversational patterns (low delay)
Streaming (Real Time)	Video/Audio streams	• Preserve time relations between entities
Interactive Best Effort	Web-browsing	• Request/Response pattern • Preserve delay (low error rate)
Background Best Effort	File transfer, e-mail	• Not time critical • Preserve payload (low error rate)

QoS Parameters (in 3G)

- Service Attributes

  - Maximum data rate
    - The highest data rate that a user could expect
  - Maximum packet/message size
  - Guaranteed data rate
    - The lowest data rate that a user is guaranteed
  - Transfer delay
    - The delay packet/message spends between access ports
  - Priority
    - Relative importance of different messages
  - Residual bit error rate
    - The undetected error rate after the delivery of the information over the service interface

QoS Parameters (Example)

Some 3G (UMTS) Service Attribute/Parameter Ranges

Traffic Class	Conversational	Streaming	Interactive	Background
Max bitrate(kbps)	<2000	<2000	<2000-overhead	<2000-overhead
Max SDU size(byte)	<1500	<1500	<1500	<1500
Guaranteed bit rate	<2000	<2000		
Transfer delay(ms)	80 - max value	500 - max value		
Priority	1,2,3	1,2,3	1,2,3	1,2,3
Residual BER	$5*10^{-2}$, 10^{-2}, 10^{-3}, , 10^{-6}	$5*10^{-2}$, 10^{-2}, 10^{-3}, , 10^{-4}, 10^{-5}, 10^{-6}	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$	$4*10^{-3}$, 10^{-5}, $6*10^{-8}$

Service Availability (QoS)

- Service denial probability
  - Probability that a user is denied to begin a session with a bearer service due to resource shortage
- Service interruption probability
  - Probability that a user is forced to terminate a session with bearer service due to resource shortage

QoS Models (Examples)

- Voice (Telephony) QoS and traffic model
  - Residual message error rate < 0.01
  - End-to-end delay fixed and not more that 80-100 mm
  - All calls have an exponentially distributed duration with average length of $1/\mu$ (time/call)
  - Relative traffic load $\rho = \lambda / \mu$: how many new calls are expected during the ongoing call. (Erlang)

  - **Service denial probability** referred to as **Blocking probability**
  - **Service interruption probability** referred **Call dropping probability**
- Web browsing QoS and traffic model
  - Short messages sent uplink from the terminal at random instant to request rather large files to be downloaded into the terminal
  - Critical QoS characteristics = response time
  - The undetected error rate at the user level < 10^{-8}
  - Classical model: Poisson distributed for the packet interval time and the size of requested files

QoS and Network Performance

- The QoS-SIR mapping => (Number of users model)
  - Is it possible to map various QoS requirements to a simple link quality measure ?
    - In a simple case => YES, we can map QoS with SIR
    - This would be difficult when:
      - » Considering the temporal aspects (e.g., message delay in non-real time)
      - » Considering the temporal variations in service availability due to traffic fluctuations and user mobility
- User behavior and service mix => (User behavior model)
  - What will be the QoS-profile requested for a certain use r and what is the required service availability ?
  - Random models used.
  - A user, with some probability belongs to a certain class of users with identical QoS profiles.
  - The probability distribution of class membership is usually referred to as service mix.

Reference

- [1] Jens Zander and Seong-Luyn Kim: Radio Resource Management for Wireless Networks, Artech House 2001,

Exercise

In a wireless network with two access ports and three terminals, the gain matrix is found to be

$$G = \begin{pmatrix} 0.02 & 0.0005 & 0.05 \\ 0.002 & 0.01 & 0.001 \end{pmatrix}$$

The transmitter power is constant (=1) and the noise power N is 0.001 for all terminals. Two orthogonal waveforms are available.

Determine the optimal access port and channel assignment and the resulting SIR.

Thank you !