EEE4121F Module A
Mobile and Wireless Networks

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In all things, it is better to hope than to despair.

Radio Resource Management

Call Admission Control

Admission Control

Admission control is used in various establishments such as:

- University- Students
- Hospital- Patients
- Hotel- Guests
- Communication network- Calls

Ensure QoS

Ensure Efficient utilization

Admission control is necessary because resources are limited

Call Admission Control

A call admission control (CAC) algorithm decides whether or not a call be accepted into a resource-constrained network without violating the service commitment made to already admitted calls

Generally, CAC algorithms are triggered by any of the following events:

- New call arrival
- Handoff call arrival
- Bearer modification

Need for Call Admission Control

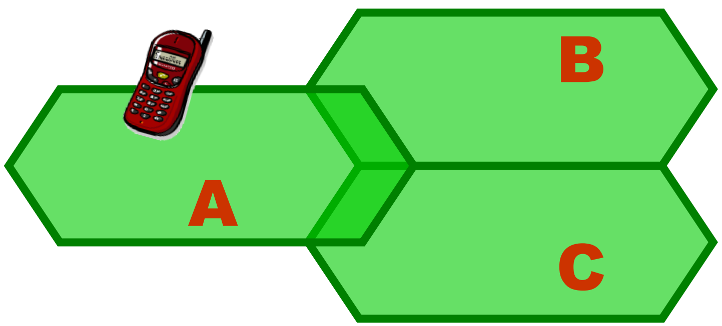
- For efficient utilization of radio resource

Network load $\approx$ Network resources — Desirable condition

Network load $>$ Network resources — Poor QoS

Network load $\ll$ Network resources — Poor resource utilization

- Service Continuity- Users' Mobility



- Service-Class Differentiation- Prioritization

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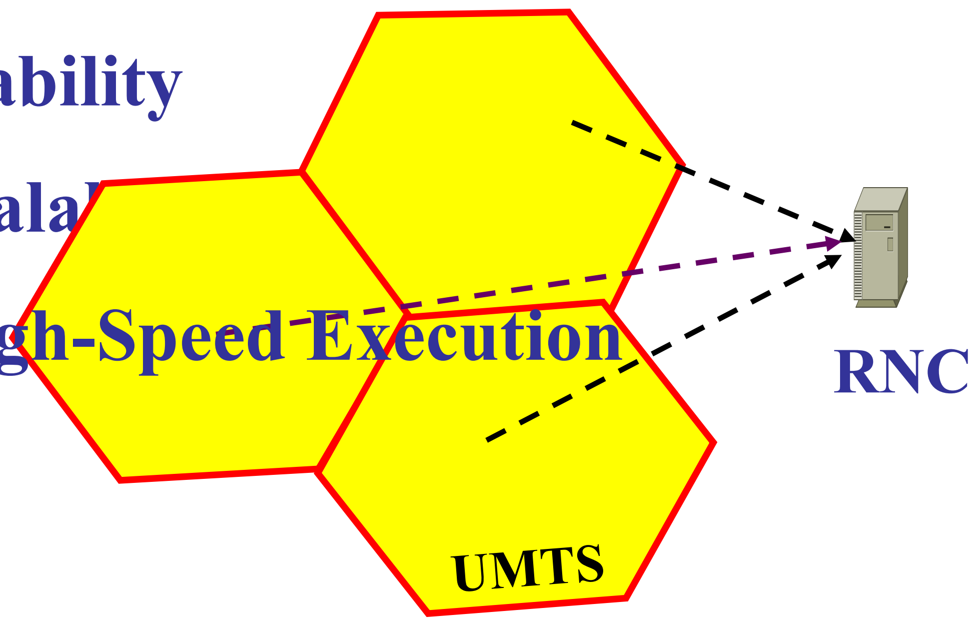
Requirements of CAC Algorithms

- Optimality
- Simplicity (not too complex)
- Minimum Information Exchange
- Stability
- Scala
- High-Speed Execution



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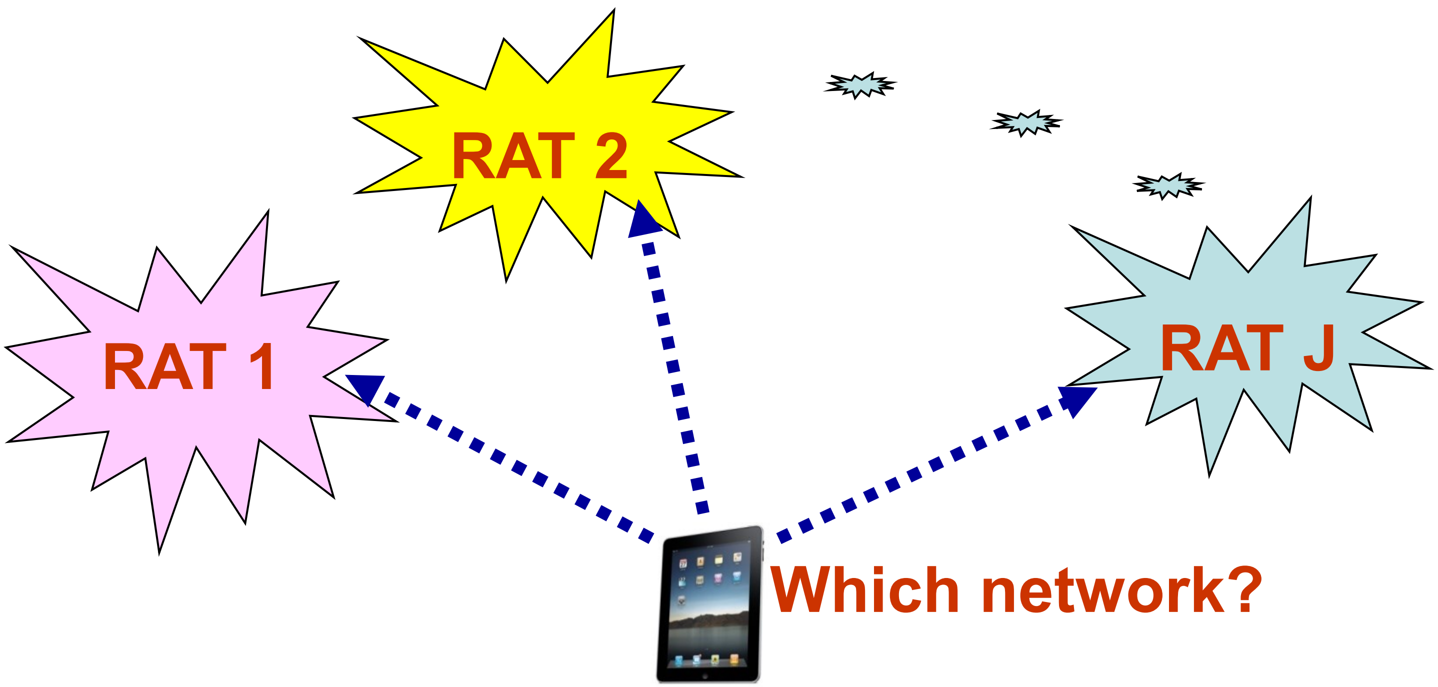
CAC Algorithms

- CAC algorithms were initially designed for homogeneous wireless networks such as GSM
- New JCAC schemes are being designed for heterogeneous wireless networks



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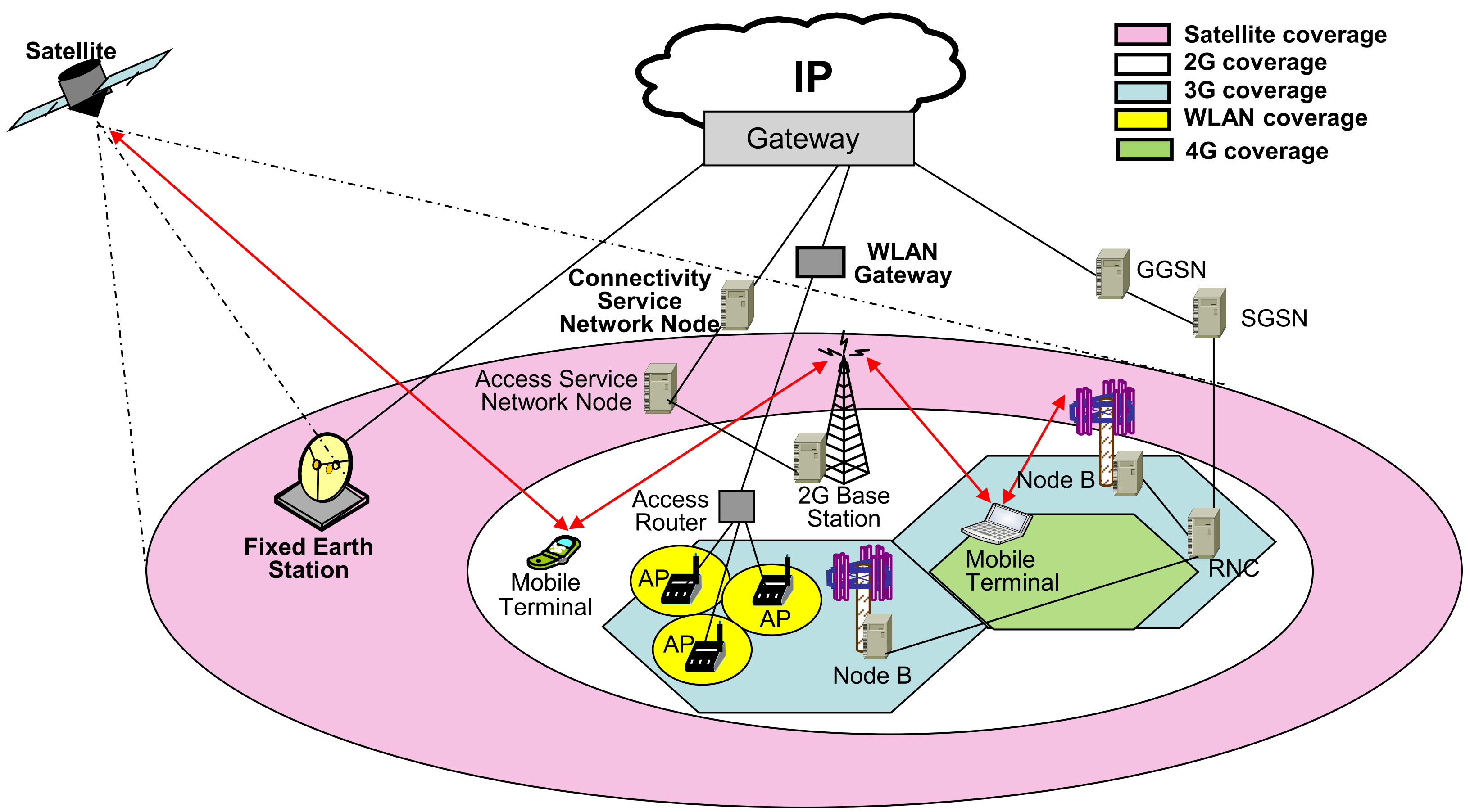
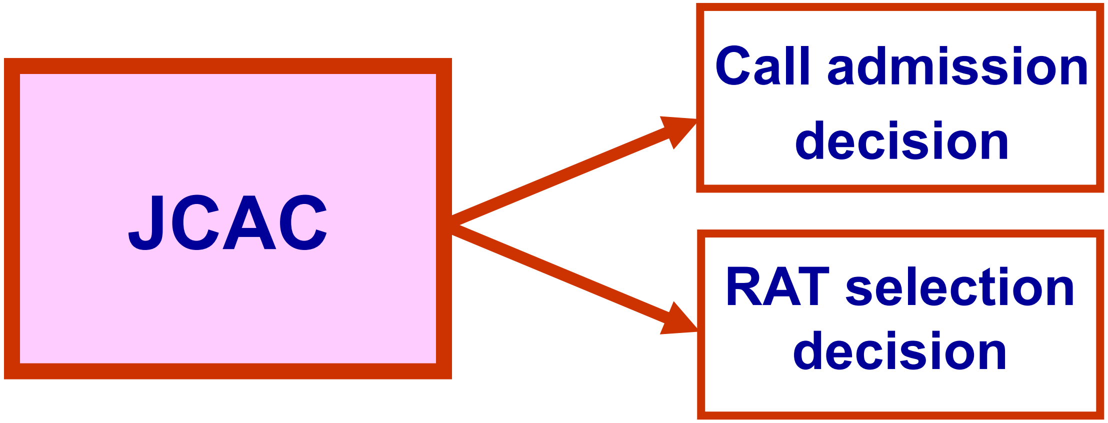
CAC in Heterogeneous Wireless Networks



- Different Radio Access Technologies (RATs) coexist
- Subscribers can seamlessly roam across different RATs

Joint CAC (JCAC) Algorithm for heterogeneous wireless network

- In heterogeneous wireless network, there is need to make RAT selection decisions in addition to call admission decisions

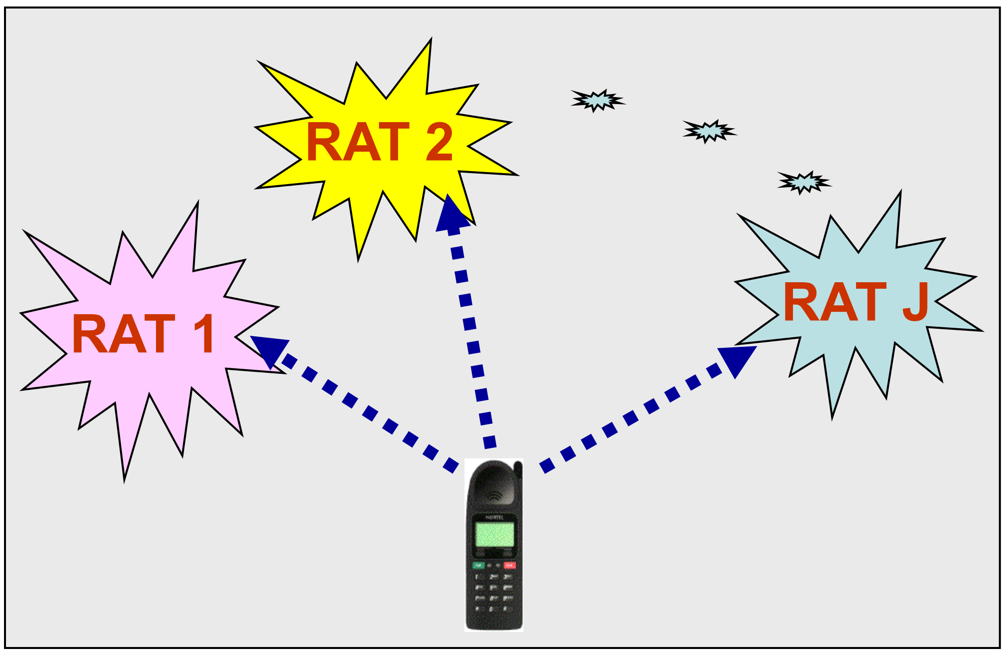


Can the arriving call be admitted or not?

Into which RAT should the call be admitted?

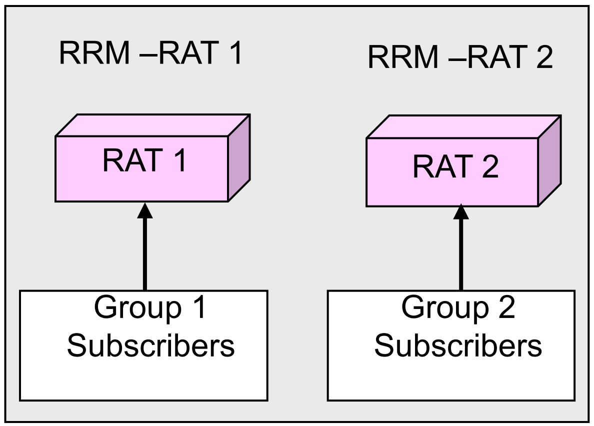
Need for JCAC

JCAC in heterogeneous wireless network is necessary for the following reasons:

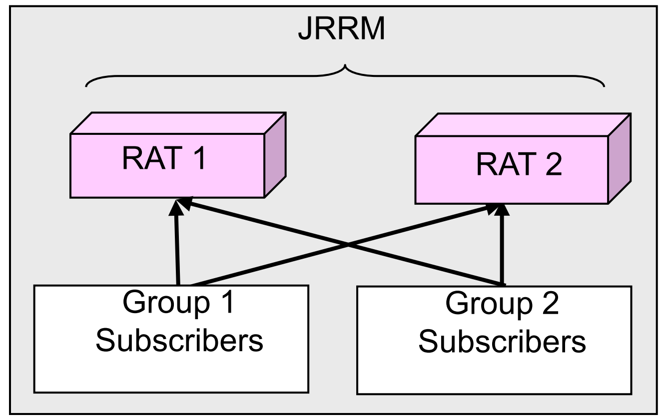


- Efficient radio resource utilization - Increased revenue
- Enhanced QoS provisioning – Improved users' satisfaction
- Overall service cost reduction
- Overall network stability

CAC in Heterogeneous Wireless Network



Independent RRM in heterogeneous wireless networks



Joint RRM in heterogeneous wireless networks

With independent RRM, each group of subscribers is confined to a single RAT, whereas with JRRM, a subscribers (using a multimode terminal) from any group can be connected through any on the available RATs that can support its class service.

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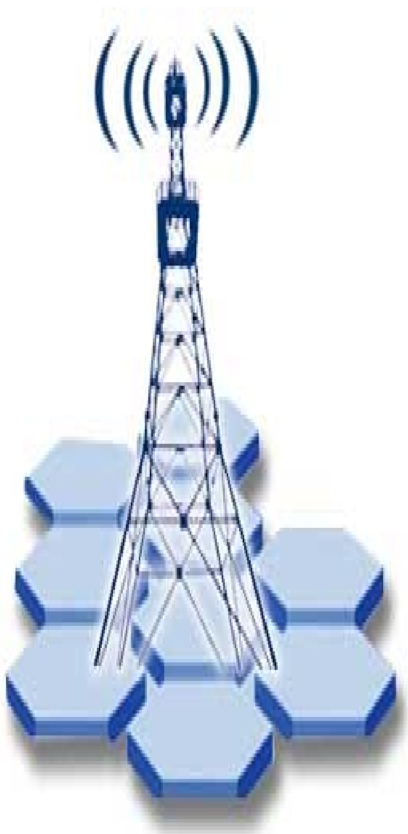
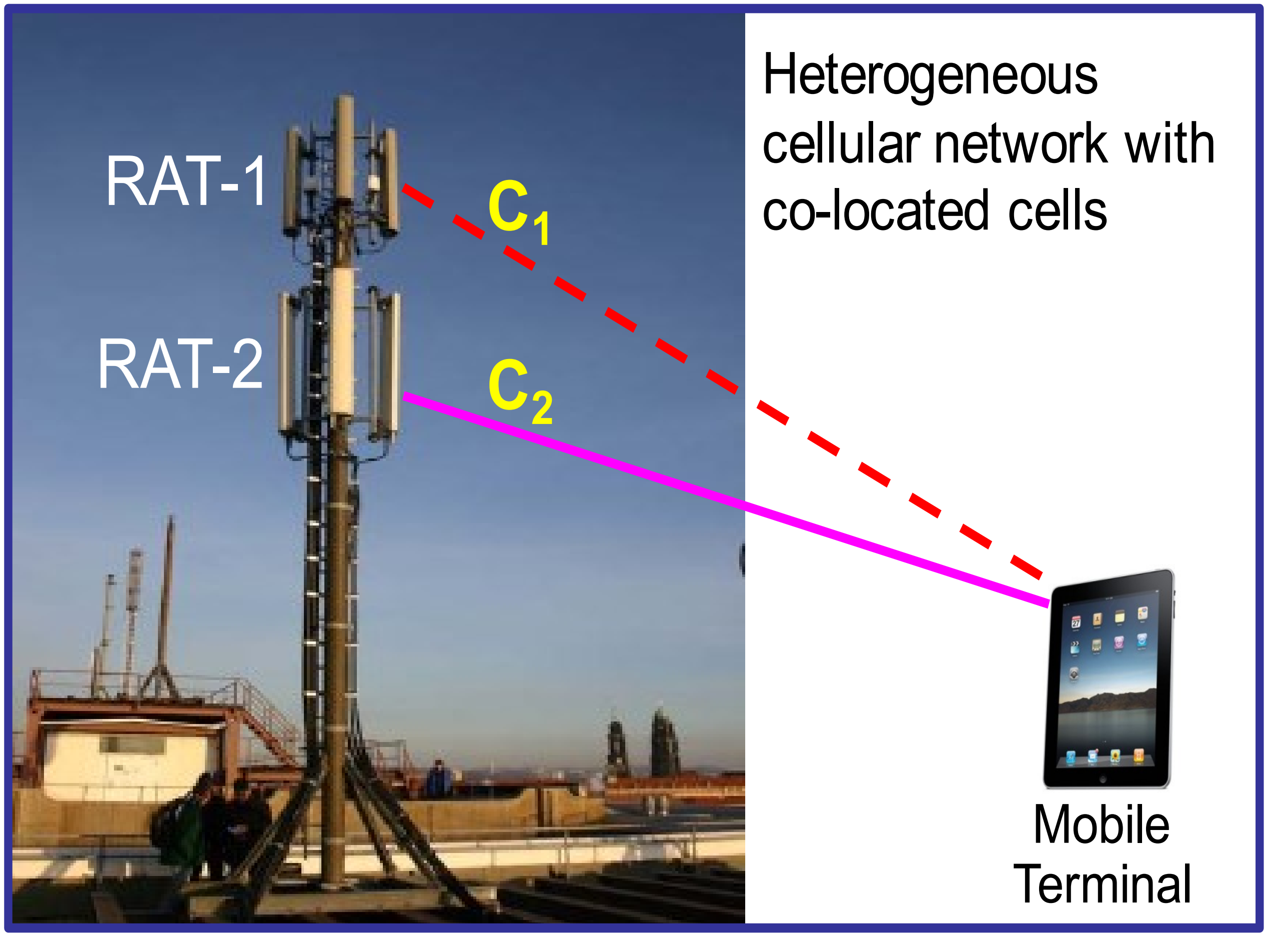
CAC in Heterogeneous Wireless Network





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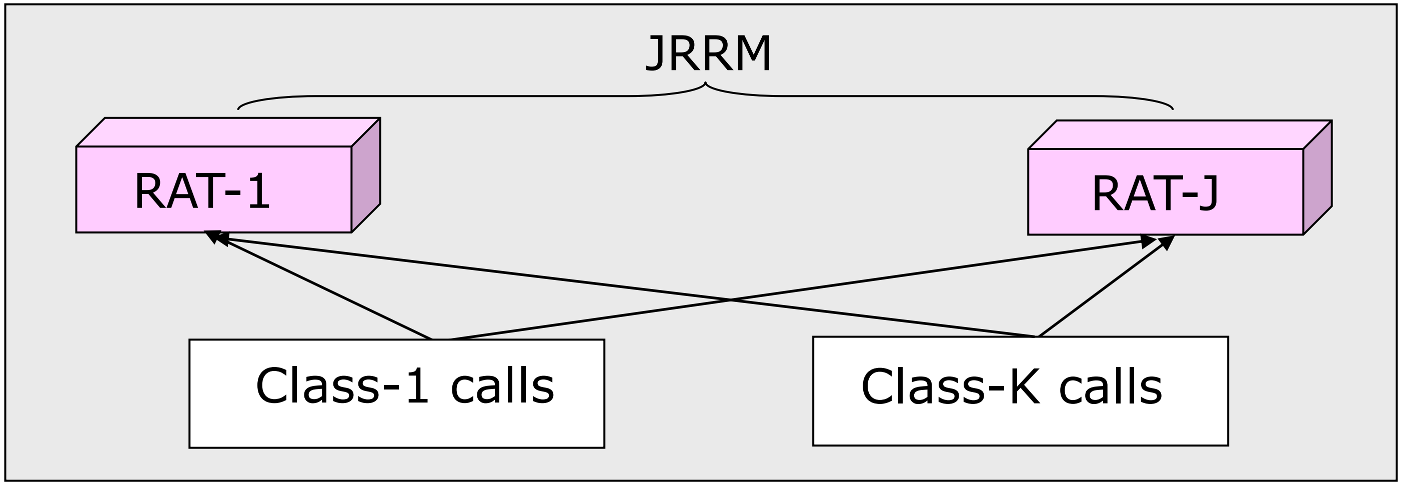
System Model: Example

- The heterogeneous network comprises J number of RATs

$$H = \{RAT-1,\ RAT-2, \cdots, RAT-J\}$$

- Supports K classes of calls

$$C = \{class-1, class-2, \cdots, class-k\}$$



Heterogeneous Network

State space of the System

$$\Omega = (m_{i,j}, n_{i,j} : i = 1, \ldots, k, \quad j = 1, \ldots, J)$$

- $m_{i,j}$ denotes number of new class-i calls in RAT j
- $n_{i,j}$ denotes number of handoff class-I calls in RAT j
- An admissible state, denoted by S, is the number of users in each class that can be simultaneously supported in the system

where $s \subset \Omega$

Action Space:

Decision Epoch- Arrival of Calls

- Set of all possible actions
- State dependent

$$A = \{a = (a_1^n, \ldots, a_k^n, a_1^h, \ldots, a_k^h):$$

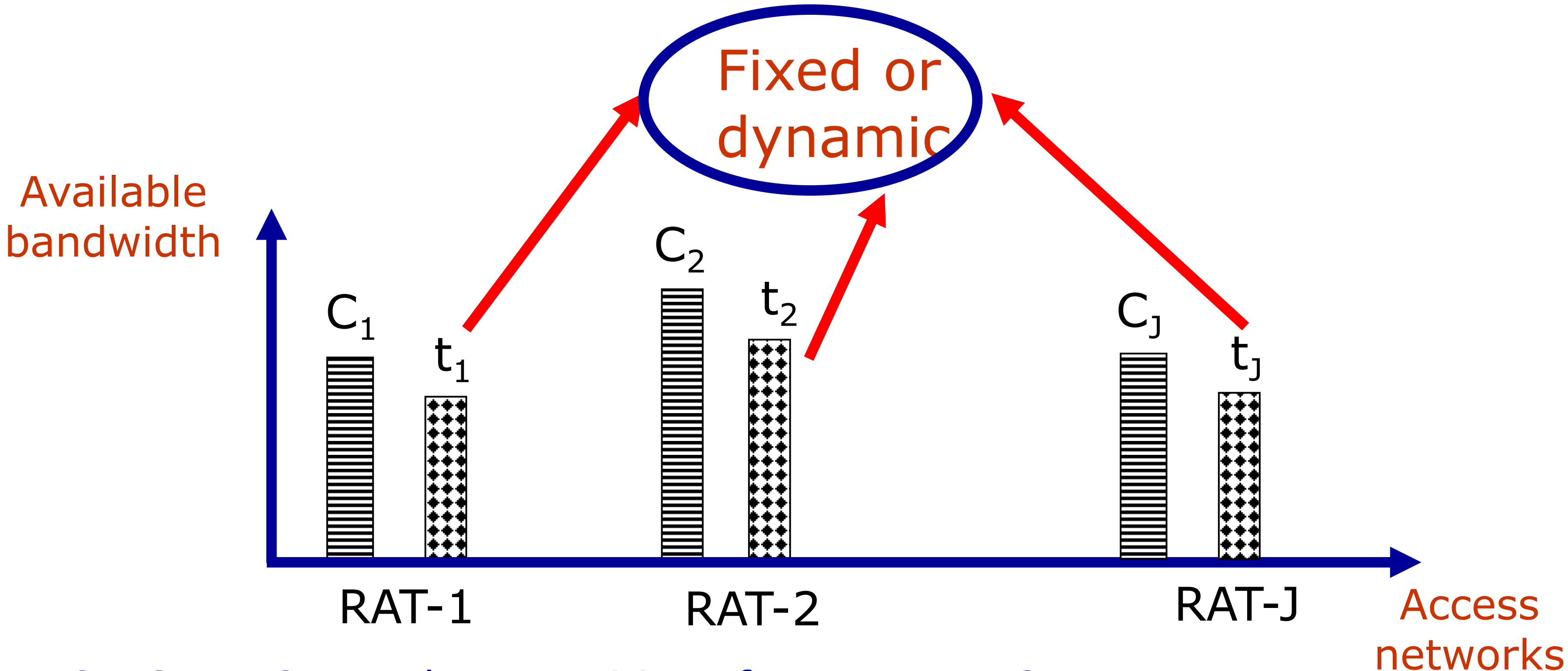
$$a_i^n, a_i^h \in (0,\ 1, \ldots, j, (j+1), \ldots, J), i = 1, \cdots, k\}$$

a_i^n denotes the action taken on arrival of a new class-i call

a_i^h denotes the action taken on arrival of a handoff class-i call

$$a_i = \begin{cases} 0; & reject\ the\ call \\ 1; & accept\ the\ call\ in\ RAT\ 1 \\ j; & accept\ the\ call\ in\ RAT\ j \end{cases}$$

Example: Bandwidth Allocation Unit



- C_1, C_2, …,C_J are the capacities of RAT-1, RAT-2,…, RAT-J, respectively.
- t_1, t_2, …,t_J are the thresholds for rejecting new calls in RAT-1, RAT-2,…, RAT-J, respectively.
- The thresholds may be fixed or dynamic. However, dynamic thresholds are more efficient.

Example: State Space

$$\Omega = (m_{i,j}, n_{i,j} : i = 1, \ldots, k, \quad j = 1, \ldots, J)$$

Admissible states of the system

$$S = \{\Omega = (m_{i,j}, n_{i,j} : i = 1, \ldots, k, \quad j = 1, \ldots, J):$$

$$\sum_{i=1}^{k} m_{i,j}\, b_i \le t_j \quad \forall j \quad \wedge$$

$$\sum_{i=1}^{k} (n_{i,j} + m_{i,j}) b_i \le C_j \quad \forall j \quad \}$$

Where:

- k is the no of classes of calls in the network
- J is the no of RATs
- m_{ij} is the no of new class-i calls in RAT-j
- n_{ij} is the no of handoff class-i calls in RAT-j
- t_j is the threshold for rejecting new calls in RAT-j
- C_j is the capacity of RAT-j
- b_i is the bandwidth required to support a single class-i call (new or handoff)

Example of Heterogeneous Wireless Network Model

A heterogeneous cellular network supporting new and handoff voice calls consists of two radio access technologies namely RAT-1 and RAT-2. RAT-1 has a capacity of 5 basic bandwidth units (bbu), RAT-2 has a capacity of 3 bbu, and each voice call requires 1bbu. In RAT-1, new calls are rejected when the current bbu being used for new calls is up to 2 whereas handoff calls are only rejected when all the available bbu are being used. In RAT-2, new calls and handoff calls are rejected only when all the available bbu are being used. There are two groups of subscribers in the heterogeneous cellular network namely Group-A and Group-B subscribers. Group-A subscribers have single-mode terminals that can connect only to RAT-1 and Group-B subscribers have dual-mode terminals that can connect to both RATs. Using the admissible state space of the heterogeneous cellular network, evaluate (i) the probability of blocking a new call from a Group-A subscriber and (ii) the probability of blocking a new call from a Group-B subscriber, (iii) the probability of dropping a handoff call from a Group-A subscriber, and (iv) the probability of dropping a handoff call from a Group-B subscriber. Assume that all states are equally probable.

Example of Heterogeneous Wireless Network Model

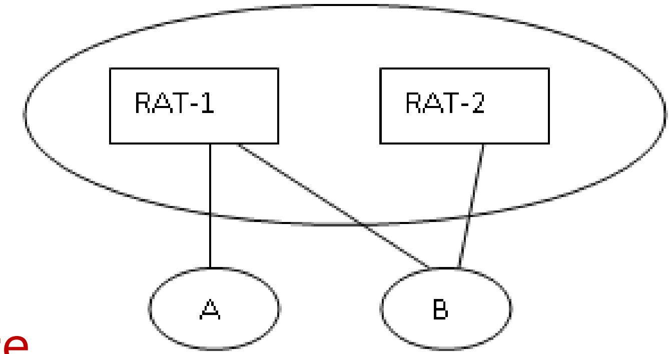


Illustration of the heterogeneous wireless network

State space

$$\Omega = (m_{i,j}, n_{i,j} : i = 1, \ldots, k, \quad j = 1, \ldots, J)$$

Parameters: K=1, J=2, b_1=1, C_1=5, t_1=2, C_2=3, t_2=3

$$\Omega = (m_{11}, n_{1,1}\ m_{12}, n_{1,2})$$

Admissible states (S)

$$S = \{\Omega = (m_{11}, n_{1,1}\ m_{12}, n_{1,2}:$$
$$m_{1,1}\ b_1 \le t_1 \wedge (m_{1,1} + n_{1,1})\, b_1 \le C_1 \wedge$$
$$m_{1,2}\ b_1 \le t_2 \wedge (m_{1,2} + n_{1,2})\, b_1 \le C_2 \quad \}$$

$$S = \{\Omega = (m_{11}, n_{1,1}\ m_{12}, n_{1,2}:$$
$$m_{1,1} \le 2 \wedge (m_{1,1} + n_{1,1}) \le 5 \wedge$$
$$m_{1,2} \le 3 \wedge (m_{1,2} + n_{1,2}) \le 3 \quad \}$$

Example of Heterogeneous Wireless Network Model

$$S = \{\Omega = (m_{11}, n_{1,1}\ m_{12}, n_{1,2}:$$

$$m_{1,1} \leq 2 \wedge (m_{1,1} + n_{1,1}) \leq 5 \wedge$$ (RAT-1)

$$m_{1,2} \leq 3 \wedge (m_{1,2} + n_{1,2}) \leq 3 \quad \}$$ (RAT-2)

Admissible states [m_{11}, n_{11}, m_{12}, n_{12}]:

[0000], [0001], [0002], [0003], [0010], [0011], [0012], [0020], [0021] [0030]
[0100], [0101], [0102], [0103], [0110], [0111], [0112], [0120], [0121] [0130]
[0200], [0201], [0202], [0203], [0210], [0211], [0212], [0220], [0221] [0230]
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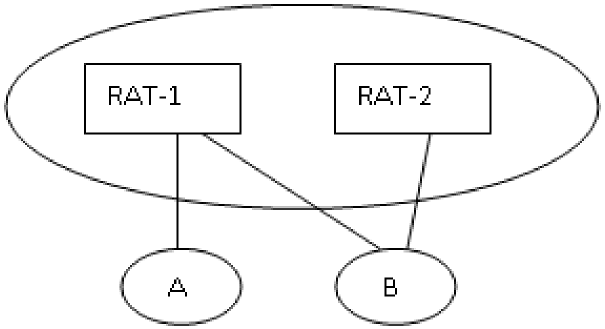
[2200], [2201], [2202], [2203], [2210], [2211], [2212], [2220], [2221] [2230]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

In all things, it is better to hope than to despair.

Example of Heterogeneous Wireless Network Model

(i) For Group-A subscribers, new call blocking states are s $\in$S, for **which**

$$(1+ m_{11}+n_{11} > 5) \vee (1+ m_{11} > 2)$$



Admissible states [m_{11}, n_{11}, m_{12}, n_{12}]:

[0000], [0001], [0002], [0003], [0010], [0011], [0012], [0020], [0021] [0030]
[0100], [0101], [0102], [0103], [0110], [0111], [0112], [0120], [0121] [0130]
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[0300], [0301], [0302], [0303], [0310], [0311], [0312], [0320], [0321] [0330]
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[2200], [2201], [2202], [2203], [2210], [2211], [2212], [2220], [2221] [2230]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

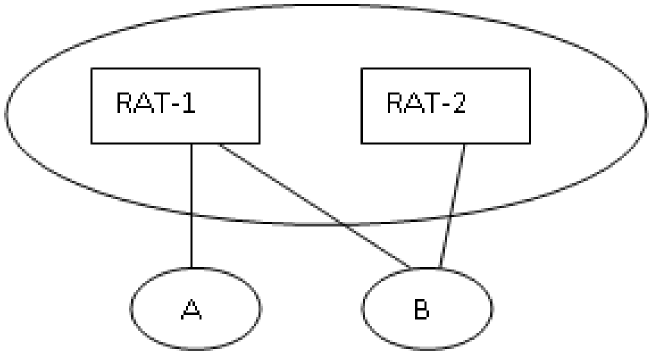
Example of Heterogeneous Wireless Network Model

(i) For Group-A subscribers, new call blocking states are $s \in S$, for which **$(1+ m_{11}+n_{11} > 5) \vee (1+ m_{11} > 2)$**

The states are:

[0500], [0501], [0502], [0503], [0510], [0511], [0512], [0520], [0521] [0530]
[1400], [1401], [1402], [1403], [1410], [1411], [1412], [1420], [1421] [1430]
[2000], [2001], [2002], [2003], [2010], [2011], [2012], [2020], [2021] [2030]
[2100], [2101], [2102], [2103], [2110], [2111], [2112], [2120], [2121] [2130]
[2200], [2201], [2202], [2203], [2210], [2211], [2212], [2220], [2221] [2230]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

Blocking probability = 6*10/15*10
=0.4



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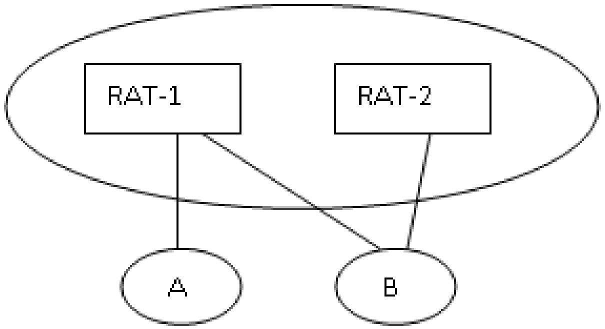
Example of Heterogeneous Wireless Network Model

(iii) For Group-A subscribers, handoff call dropping states are s $\in$S, for which

$$(1+ m_{11}+n_{11}) > 5$$



Admissible states [m_{11}, n_{11}, m_{12}, n_{12}]:

[0000], [0001], [0002], [0003], [0010], [0011], [0012], [0020], [0021] [0030]
[0100], [0101], [0102], [0103], [0110], [0111], [0112], [0120], [0121] [0130]
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[2200], [2201], [2202], [2203], [2210], [2211], [2212], [2220], [2221] [2230]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

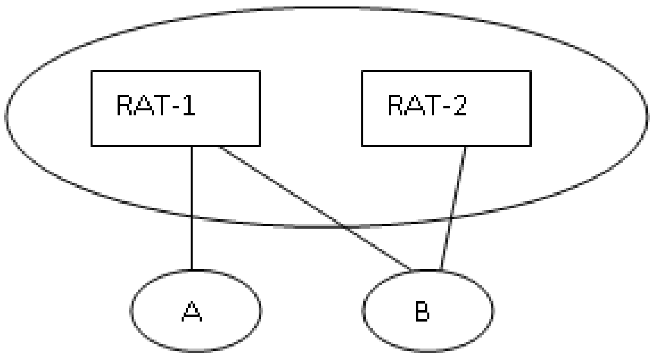
Example of Heterogeneous Wireless Network Model

(iii) For Group-A subscribers, new call blocking states are $s \in S$, for which $((1+ m_{11}+n_{11}) > 5)$

The states are

[0500], [0501], [0502], [0503], [0510], [0511], [0512], [0520], [0521] [0530]
[1400], [1401], [1402], [1403], [1410], [1411], [1412], [1420], [1421] [1430]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

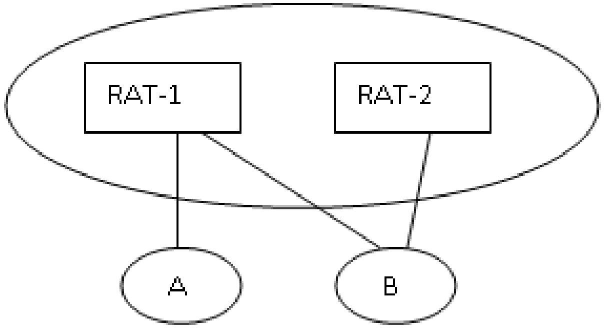
Dropping probability = 3*10/15*10
=0.2



Example of Heterogeneous Wireless Network Model

(ii) For Group-B subscribers, new blocking states are $s \in S$, for which

$$(((1+ m_{11}+n_{11}) > 5) \vee (1+ m_{11}) > 2)) \wedge$$
$$((1+ m_{12}+n_{12}) > 3)$$



Admissible states [m_{11}, n_{11}, m_{12}, n_{12}]:

[0000], [0001], [0002], [0003], [0010], [0011], [0012], [0020], [0021] [0030]
[0100], [0101], [0102], [0103], [0110], [0111], [0112], [0120], [0121] [0130]
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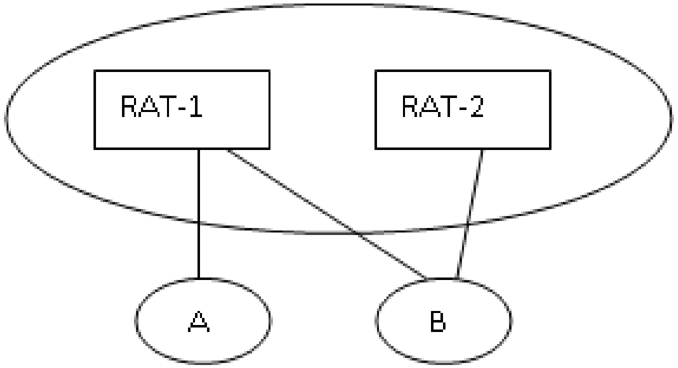
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

Example of Heterogeneous Wireless Network Model

(ii) For Group-B subscribers, new blocking states are s $\in$S, for which

$(((1+ m_{11}+n_{11}) > 5) \vee (1+ m_{11}) > 2)) \wedge$
$((1+ m_{12}+n_{12}) > 3)$



[0503], [0512], [0521] [0530]
[1403], [1412], [1421] [1430]
[2003], [2012], [2021] [2030]
[2103], [2112], [2121] [2130]
[2203], [2212], [2221] [2230]
[2303], [2312], [2321] [2330]

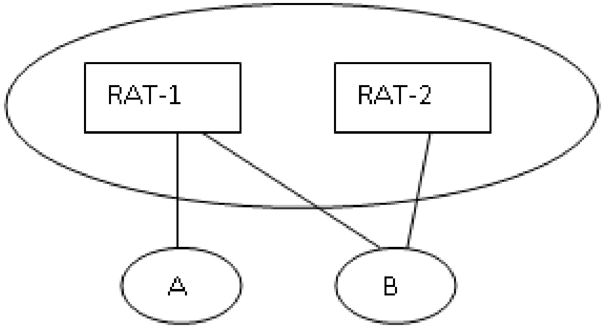
Blocking probability = 6*4/15*10
= 0.16

Example of Heterogeneous Wireless Network Model

(iv) For Group-B subscribers, new blocking states are $s \in S$, for which

$((1+ m_{11}+n_{11}) > 5\ ) \wedge$

$((1+ m_{12}+n_{12}) > 3\ )$



Admissible states [m_{11}, n_{11}, m_{12}, n_{12}]:

[0000], [0001], [0002], [0003], [0010], [0011], [0012], [0020], [0021] [0030]
[0100], [0101], [0102], [0103], [0110], [0111], [0112], [0120], [0121] [0130]
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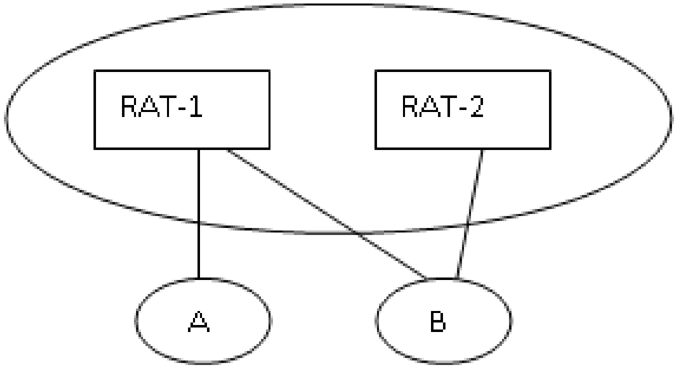
[0400], [0401], [0402], [0403], [0410], [0411], [0412], [0420], [0421] [0430]
[0500], [0501], [0502], [0503], [0510], [0511], [0512], [0520], [0521] [0530]
[1000], [1001], [1002], [1003], [1010], [1011], [1012], [1020], [1021] [1030]
[1100], [1101], [1102], [1103], [1110], [1111], [1112], [1120], [1121] [1130]
[1200], [1201], [1202], [1203], [1210], [1211], [1212], [1220], [1221] [1230]
[1300], [1301], [1302], [1303], [1310], [1311], [1312], [1320], [1321] [1330]
[1400], [1401], [1402], [1403], [1410], [1411], [1412], [1420], [1421] [1430]
[2000], [2001], [2002], [2003], [2010], [2011], [2012], [2020], [2021] [2030]
[2100], [2101], [2102], [2103], [2110], [2111], [2112], [2120], [2121] [2130]
[2200], [2201], [2202], [2203], [2210], [2211], [2212], [2220], [2221] [2230]
[2300], [2301], [2302], [2303], [2310], [2311], [2312], [2320], [2321] [2330]

In all things, it is better to hope than to despair.

Example of Heterogeneous Wireless Network Model

(iv) For Group-B subscribers, handoff call dropping states are $s \in S$, for which $((1+ m_{11}+n_{11}) > 5) \wedge ((1+ m_{12}+n_{12}) > 3))$



[0503], [0512], [0521] [0530]
[1403], [1412], [1421] [1430]
[2303], [2312], [2321] [2330]

Dropping probability = 4*3/15*10=0.08

Exercise 1a: Do the exercise below

A heterogeneous cellular network supporting new and handoff voice calls consists of two radio access technologies namely RAT-1 and RAT-2. RAT-1 has a capacity of 4 basic bandwidth units (bbu), RAT-2 has a capacity of 3 bbu, and each voice call requires 1bbu. In RAT-1, new calls are rejected when the current bbu being used for new calls is up to 3 whereas handoff calls are only rejected when all the available bbu are being used. In RAT-2, new calls are rejected when the current bbu being used for new call is up to 2 whereas handoff calls are only rejected when all the available bbu are being used. There are two groups of subscribers in the heterogeneous cellular network namely Group-A and Group-B subscribers. Group-A subscribers have single-mode terminals that can connect only to RAT-1 and Group-B subscribers have double-mode terminals that can connect to both RATs. Using the admissible state space of the heterogeneous cellular network, evaluate (i) the probability of blocking a new call from a Group-A subscriber and (ii) the probability of blocking a new call from a Group-B subscriber, (iii) the probability of dropping a handoff call from a Group-A subscriber, and (iv) the probability of dropping a handoff call from a Group-B subscriber. Assume that all states are equally probable.

Exercise 1b: Do the exercise below

Write a simple code to calculate the following:
(i) the probability of blocking a new call from a Group-A subscriber and (ii) the probability of blocking a new call from a Group-B subscriber, (iii) the probability of dropping a handoff call from a Group-A subscriber, and (iv) the probability of dropping a handoff call from a Group-B subscriber. Assume that all states are equally probable.

EEE4121F Module A

He who will attain the incredible must attempt the impossible.

Never admit failure until you have made your last attempt.
Never make your last attempt until you have succeeded.

Every problem has a shelf life and an expiry date.

Never give up!

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In all things, it is better to hope than to despair.