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 and load balancing in heterogenous wireless networks

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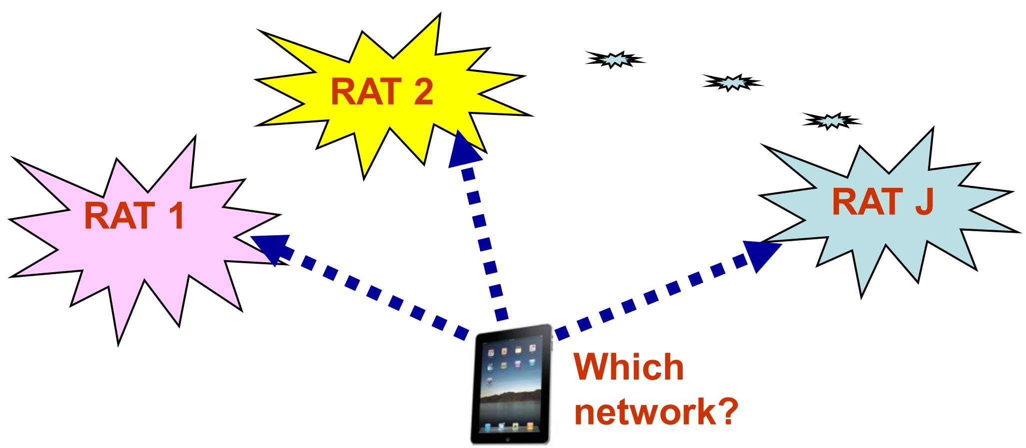
RAT selection approaches and categorization of JCAC algorithms

- JCAC algorithms
  - Single-criterion
    - Random-selection based
    - Network-load based
    - Service-cost based
    - Path-loss based
    - Service-class based
    - Layer based
    - **Terminal –modality based**
  - Multiple-criteria
    - Non computational intelligence based
    - Computational intelligence based



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RAT selection approaches and categorization of JCAC algorithms

Approach	Main Idea	Advantage	Disadvantage
Random selection-based	Calls are randomly admitted into any of the available RATs	Simple	Not efficient, high blocking probability
Network-load-based	Calls are admitted into the least loaded RAT in the heterogeneous network such that network load is almost the same for all the available access network	High network stability due to uniform load distribution	Network centric, hence low user satisfaction
Service-cost -based	Calls are admitted into the least expensive RAT such that the subscriber incurs the least service cost in the heterogeneous network	Reduced overall service cost	Unbalanced network load
Path-loss-based	Calls are admitted based on path-loss measurement.	Lower bit-error rate and higher throughput	High frequency of vertical handover

RAT selection approaches and categorization of JCAC algorithms

Approach	Main Idea	Advantage	Disadvantage
Service-class-based	Calls are admitted into a particular RAT based on the class of service	High QoS	Unbalanced network load
Layer-based	Calls are admitted based on layers, starting from the upper layer. If the current layer is loaded, JCAC tries the next lower layer.	Simple	Highly unbalanced network load
Non computational intelligence-based	Calls are admitted into a particular RAT based on some cost function or utility function derived from multiple criteria without the use of computational intelligence techniques	Efficient, maximize some objective function, and improve users satisfaction	High computational overhead, complex
Computational intelligence-based	Calls are admitted into a particular RAT, which is chosen by applying a computational intelligence technique (e.g., fuzzy logic) to some RAT selection criteria	Efficient, improves users satisfaction function	Complicated

Design considerations for JCAC algorithms

Design Consideration	Design options	Advantage	Disadvantage	Comment
Centralization	Centralized	More efficient	Complex, non-scalable, high signaling overhead, not-fault tolerant	Impractical
	Distributed	Scalable, simple	Less efficient	Commonly used
Centricity	Network-centric	High efficiency and improved overall network management	More complex	-
	User-centric	Enhance users satisfaction	Unbalanced heterogeneous network load	Preferable to subscribers

Design considerations for JCAC algorithms

Design Consideration	Design options	Advantage	Disadvantage	Comment
Network selection criteria	Single criterion e.g., network load, call service class, etc.	Simple	Less efficient	-
	Multiple criteria	More efficient	Cumbersome	Often incorporate Fuzzy logic, Fuzzy MADM technique, etc.
Call type	Initial RAT selection	Simple	-	Selects RAT new calls
	Handoff RAT selection		More complicated	Selects RAT for vertical handoff calls

Design considerations for JCAC algorithms

Design Consideration	Design options	Advantage	Disadvantage	Comment
Optimality	Optimal	More efficient	Complex	More desirable, incorporates optimization techniques e.g., linear programming, genetic algorithm
	Sub optimal	More realistic, scalable	Less efficient	More realistic
Prediction	Predictive	More efficient	More error-prone	Performance depends on the accuracy of the predicted information
	Non-predictive	Simple, more accurate	Less efficient	-

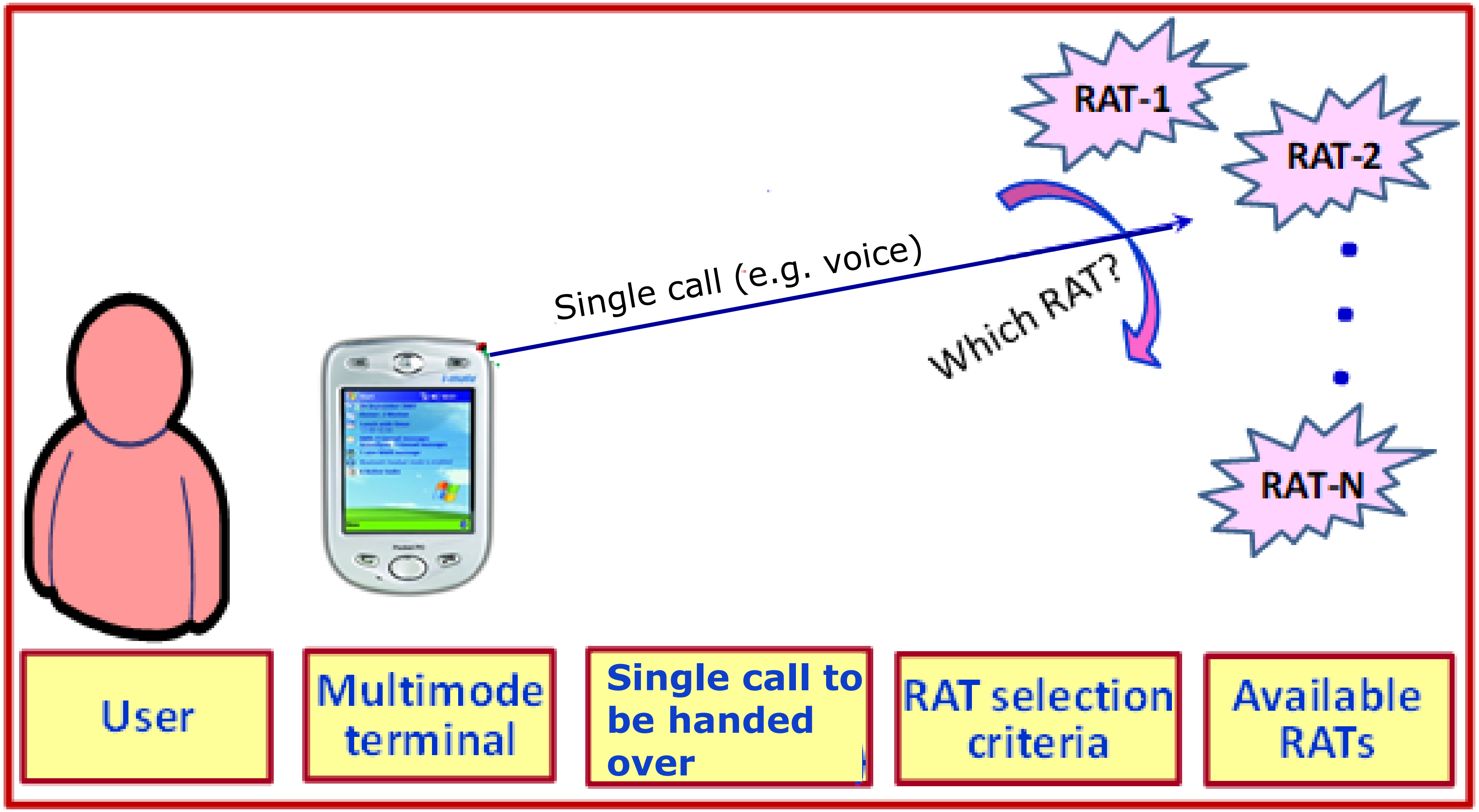
RAT selection based on user's preferences

Users' Preferences	Advantage
Least service cost	Reduces overall service cost incurred by subscribers
Minimum delay (s)	Enhances quality of service
Maximum data rate (Kbps or Mbps)	Reduces service-delivery time for non-real-time services, enhances quality of service for adaptive real-time services
Widest coverage (m or Km)	Reduces handoff frequency for highly mobile subscribers
Least battery power consumption	Increases battery lifetime and reduces recharge frequency
Highest network security	Enhances information confidentiality and integrity

RAT selection criteria based on operators' preferences

Operators' Preferences	Advantage
Uniform load distribution	Enhances overall network stability. Prevent over subscription of some RATs
Revenue maximization	Increases operator's revenue
Call blocking/dropping minimization	Enhances connection-level QoS
Optimal radio resource utilization	Improves radio resource utilization efficiency

Single-Call RAT Selection



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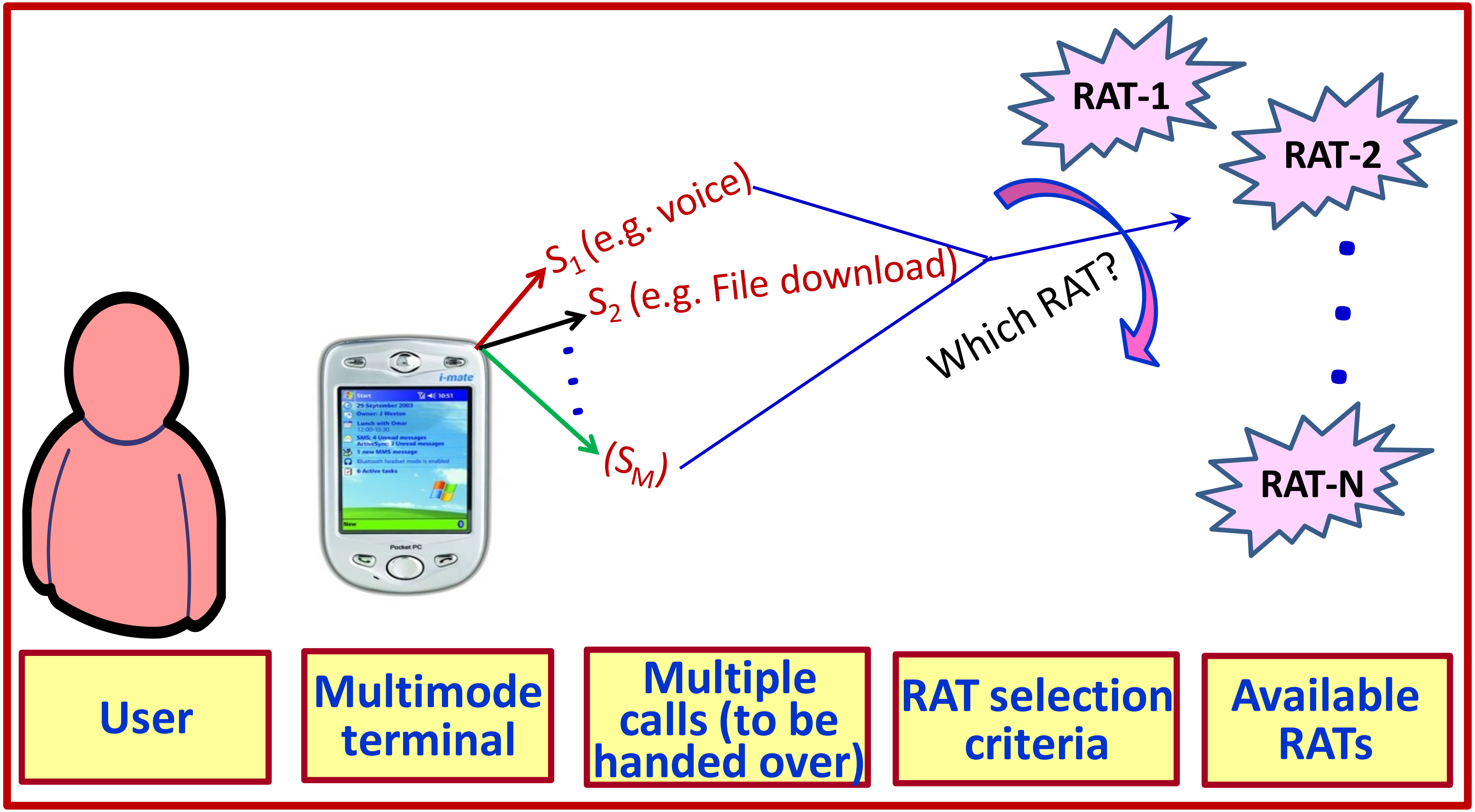
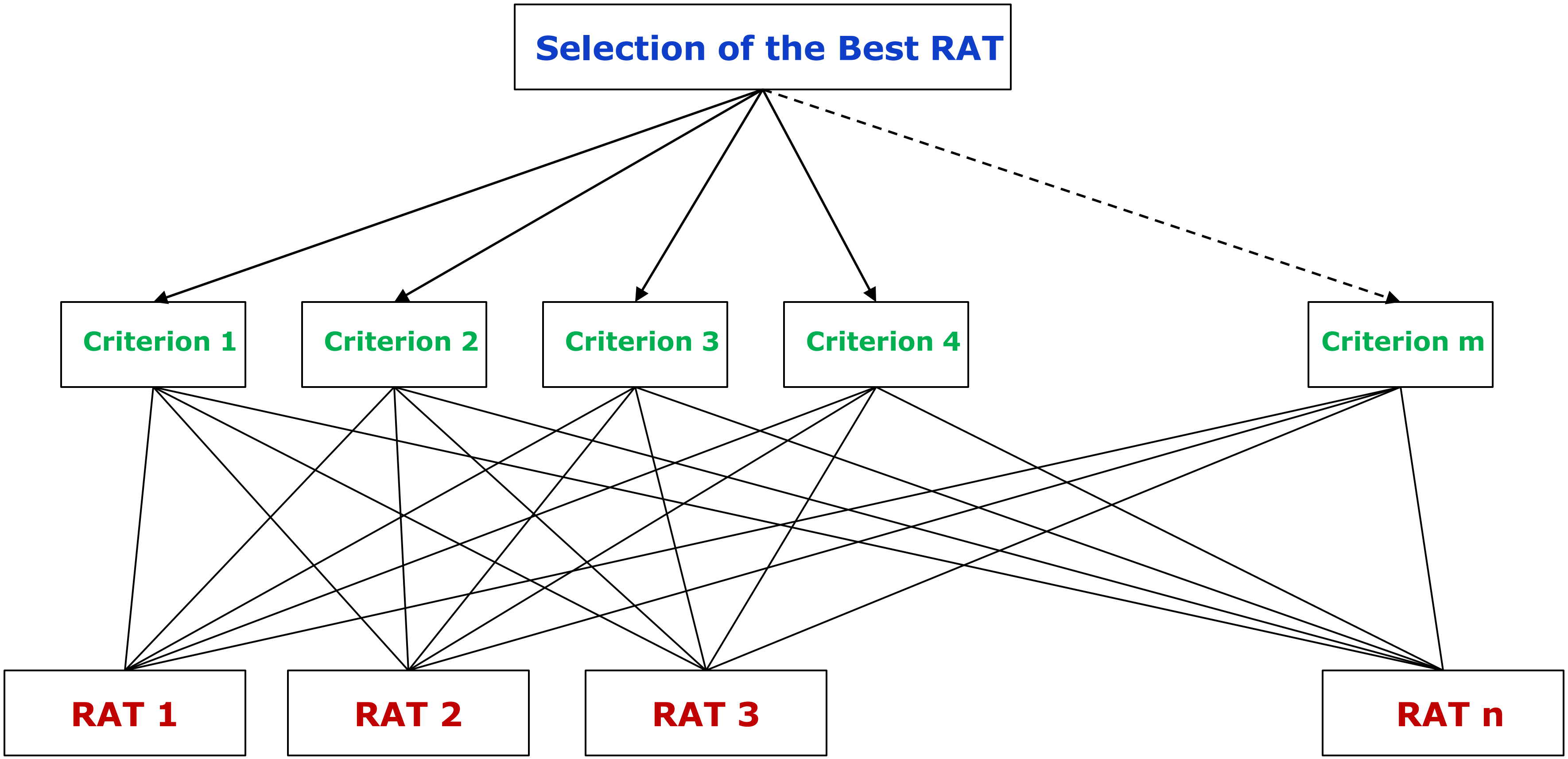
Single-Call Versus Multiple-Call RAT Selection



RAT Selection Based on MADM/MCDM Techniques



MADM (Multi-attribute Decision Making)
MCDM (Multi-criteria Decision Making)

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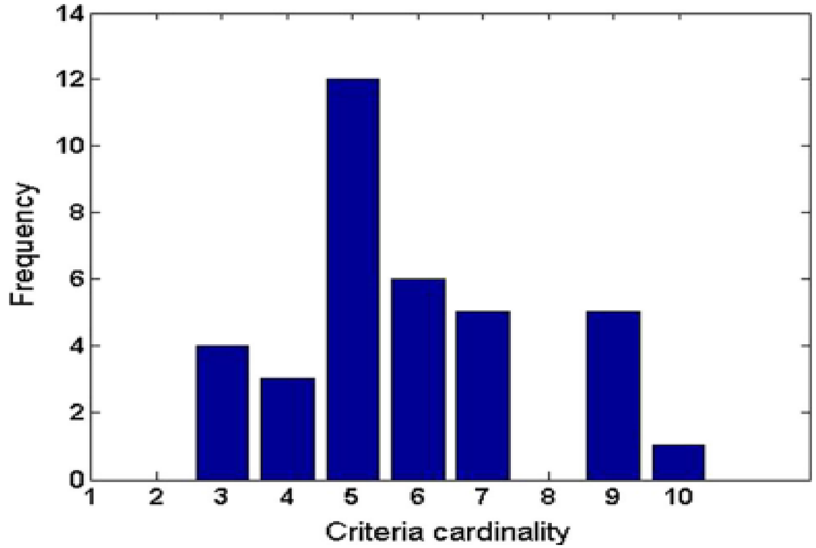
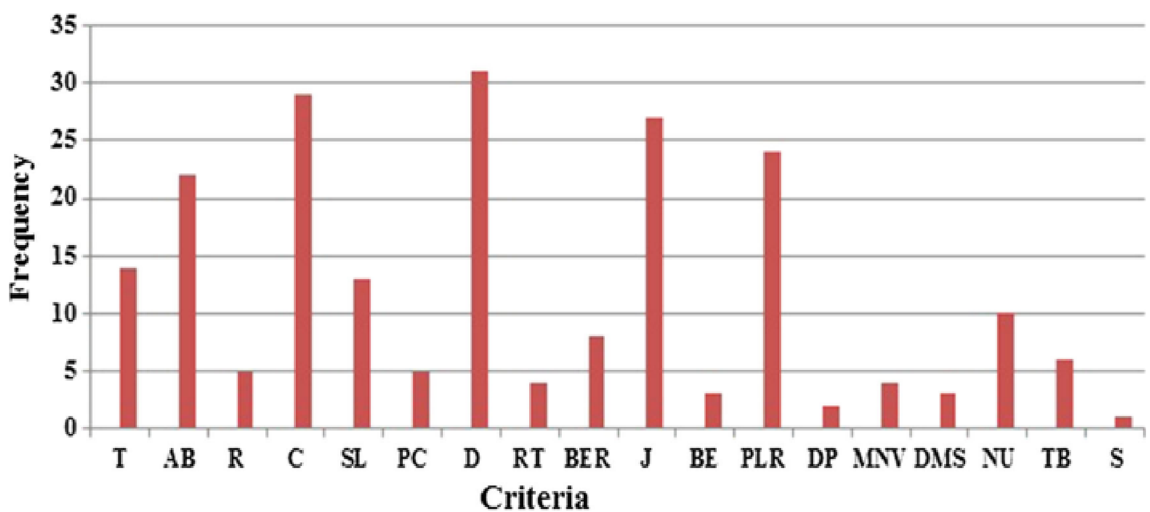
Examples of RAT Selection Criteria

- Throughput (T)
- Allowed bandwidth (AB)
- RSS (R)
- Cost (C)
- Security level (SL)
- Power consumption (PC)
- Delay (D)
- Response time (RT)
- Bit error rate (BER)
- Jitter (J)
- Burst error (BE)
- Packet loss rate (PLR)
- Dropping probability (DP)
- MN velocity (MNV)
- Device memory size (DMS)
- Network utilization (NU)
- Total bandwidth (TB)
- SINR (S)



Frequency of criteria cardinality in reviewed papers



Frequency of criteria in reviewed papers

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(A) Illustration of MADM/MCDM Technique (SAW)

Illustration of a procedure for making handover decisions in a heterogeneous wireless network

(1) Specify the call to be handed over, the set of available RATs, the set of RAT-selection criteria, and the user-defined weights for RAT selection

(2) Construct the decision matrix (D)

(3) Calculate the normalised decision matrix (D')

(4) Normalise the weights assigned by the user for the class of call. (Each user would provide his/her preference information for a particular RAT for each class of calls. This preference information is specified in terms of weight.)

(5) Calculate the score metric for each RAT using an MADM technique

(6) Select the RAT with the highest score for the call

Illustration of MADM/MCDM Technique

(1) Specify the call to be handed over, the set of available RATs, the set of RAT-selection criteria, and the user-defined weights for RAT selection

- Assume there are N available RATs (RAT-1, RAT-2, …, RAT-N)
- Each RAT has X criteria (Criterion-1, Criterion-2, …, Criterion-X)
- Candidate RAT & criterion are denoted by j & *x* respectively
- For each class of calls, each user assigns weight w_x to each of the RAT-selection criteria.

Illustration of MADM/MCDM Technique

(2) Construct the Decision Matrix

$$
D = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array}
\begin{array}{c}
\begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\
\begin{bmatrix}
m_{11} & m_{12} & \cdots & m_{1X} \\
m_{21} & m_{22} & \cdots & m_{2X} \\
\vdots & \vdots & \cdots & \vdots \\
m_{N,1} & m_{N,2} & \cdots & m_{N,X}
\end{bmatrix}
\end{array}
$$

where

m_{11} – Criterion 1 of RAT 1

m_{1X} – Criterion X of RAT 1

m_{N1} – Criterion 1 of RAT N

m_{NX} – Criterion X of RAT N

Illustration of MADM/MCDM Technique

(3) Calculate the Normalised Decision Matrix (D')

- In MCDM problems, there are benefit criteria (e.g., throughput) and cost criteria (e.g., cost), and the 'dimension' of the criteria may be different
- In order to measure all criteria in dimensionless units and to facilitate their comparison, normalisation is necessary
- There are different ways of normalizing the values of the criteria, and the following method is an example:

$$b_{j,x} = \begin{cases} \dfrac{m_{j,x}}{\max\{m_{j,x} \mid j=1,2,\ldots,J\}}, & \textit{for benefit criterion } C_x \\[2ex] \dfrac{\min\{m_{ij} \mid j=1,2,\ldots,J\}}{m_{j,x}}, & \textit{for cost criterion } C_x \end{cases}$$

where b_{jx} is the normalized performance rating of RAT j on criterion C_x

Illustration of MADM/MCDM Technique

(4) Calculate the Normalised Weight

- In MCDM problems, each user would provide his/her preference information for a particular RAT for each class of calls. This preference information is specified in terms of weight attached to each network criterion by the user.
- The weighing vector, W_i represents the relative importance of the criteria to user i, and it is given as:

$$W = \{ w_1 \quad w_2 \quad \cdots \quad w_X \}$$

The weighing vector is normalized as follows:

$$\overline{W} = \{ \overline{w}_1 \quad \overline{w}_2 \quad \cdots \quad \overline{w}_X \}$$

$$\overline{w}_v = \frac{w_v}{\sum_{u=1}^{X} w_u} \qquad v = 1, 2, \cdots, X$$

- For example, a 10-point weigth scale = {0, 1,2,3,4,5,6,7,8,9}

Illustration of MADM/MCDM Technique

(5) Calculate the score metric for each RAT using an MADM technique (e.g., SAW or MEW)

- Using SAW (Simple Additive Weighting, the normalized decision matrix (D ') and the aggregated weighting vector (01) are used to rank the alternative RATs for the handoff call from multimode terminal. The preference ratings of the available RATs for the call to be handed over are obtained as:

$$v_j = \sum_{n=1}^{X} \overline{w}_n \times b_{j,n} \quad \forall\, j = 1,\ldots,N$$

Illustration of MADM/MCDM Technique

(6) Select the RAT with the highest score for the call

- The RATs are ordered according to their ranking values obtained in step 5. The highest-ranking RAT is then selected as the most appropriate RAT for the set of handoff call from the mobile terminal. If two or more RATs have the same highest ranking value, the less loaded of the two RATs will be selected from the handoff call.

Example of RAT Selection Using SAW Technique

Given the following RATs and RAT-selection criteria in a two-RAT heterogeneous wireless network supporting data call, select the appropriate RAT for each of the three users with the following weight vectors.

(STEP 1)

RATs	Criteria	
	Price (Rand per MB)	Available data rate per user (Mbps)
RAT 1 (WLAN)	0.1	54
RAT 2 (5G)	0.5	100

User-x, W={weight_price, weight_data rate}
User-1, W={1, 10}
User-2, W={5, 5}
User-3, W={2, 8}

Weight values are from a10-point weight scale = {0, 1,2,3,4,5,6,7,8,9}

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Example of RAT Selection Using SAW Technique

(STEP 2) The Decision Matrix is:

$$
\begin{array}{cc}
 & \begin{array}{cc} c_1 & c_2 \end{array} \\
D = \begin{array}{c} R_1 \\ R_2 \end{array} & \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}
\end{array}
$$

$$
\begin{array}{cc}
 & \begin{array}{cc} c_1 & c_2 \end{array} \\
D = \begin{array}{c} R_1 \\ R_2 \end{array} & \begin{bmatrix} 0.1 & 54 \\ 0.5 & 100 \end{bmatrix}
\end{array}
$$

Example of RAT Selection Using SAW Technique

(Step 3) The Normalised Decision (D') Matrix is:

$$D' = \begin{array}{c|cc} & c_1 & c_2 \\ \hline R_1 & 0.1/0.1 & 54/100 \\ R_2 & 0.1/0.5 & 100/100 \end{array}$$

$$D' = \begin{array}{c} \\ R_1 \\ R_2 \end{array} \begin{array}{c} \begin{matrix} c_1 & c_2 \end{matrix} \\ \begin{bmatrix} 1 & 0.54 \\ 0.2 & 1 \end{bmatrix} \end{array}$$

Note that price (C1) is a cost attribute and data rate (C2) is a benefit attribute.

Example of RAT Selection Using SAW Technique

(Step 4) Calculate the Normalised Weight ($\overline{W}$):

$$\overline{w}_v = \frac{w_v}{\sum_{u=1}^{X} w_u} \qquad v = 1, 2, \cdots, X$$

User-1, W={1, 10}; $\overline{W}$={0.09, 0.91}

User-2, W={5, 5} ; $\overline{W}$={0.5, 0.5}

User-3, W={2, 8}; $\overline{W}$={0.2, 0.8}

Example of RAT Selection Using SAW Technique

(Step 5) Calculate the score metric for each RAT using SAW technique

$$v_j = \sum_{n=1}^{X} \overline{w}_n \times b_{j,n} \quad \forall j = 1, \ldots, N$$

User-1, $\overline{W}$={0.09, 0.91}

User-2, $\overline{W}$={0.5, 0.5}

User-3, $\overline{W}$={0.2, 0.8}

$$D' = \begin{array}{c c} & \begin{array}{cc} c_1 & c_2 \end{array} \\ \begin{array}{c} R_1 \\ R_2 \end{array} & \begin{bmatrix} 1 & 0.54 \\ 0.2 & 1 \end{bmatrix} \end{array}$$

For User-1, RAT-1 score = (0.09x1) + (0.91x0.54) = 0.5814

RAT-2 score = (0.09x0.2) + (0.91x1) = 0.928

Selected RAT = RAT-2 (0.928 > 0.514)

Example of RAT Selection Using SAW Technique

(Step 5) Calculate the score metric for each RAT using SAW technique

User-1, $\overline{W}$={0.09, 0.91}

User-2, $\overline{W}$={0.5, 0.5}

User-3, $\overline{W}$={0.2, 0.8}

$$D' = \begin{array}{c c} & \begin{array}{cc} c_1 & c_2 \end{array} \\ \begin{array}{c} R_1 \\ R_2 \end{array} & \begin{bmatrix} 1 & 0.54 \\ 0.2 & 1 \end{bmatrix} \end{array}$$

For User-2, RAT-1 score = (0.5x1) + (0.5x0.54) = 0.77

RAT-2 score = (0.5x0.2) + (0.5x1) = 0.6

Selected RAT = RAT-1 (0.77 > 0.6)

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Example of RAT Selection Using SAW Technique

(Step 5) Calculate the score metric for each RAT using SAW technique

User-1, $\overline{W}=\{0.09, 0.91\}$

User-2, $\overline{W}=\{0.5, 0.5\}$

User-3, $\overline{W}=\{0.2, 0.8\}$

$$D' = \begin{array}{c} \\ R_1 \\ R_2 \end{array} \begin{array}{c} \begin{array}{cc} c_1 & c_2 \end{array} \\ \begin{bmatrix} 1 & 0.54 \\ 0.2 & 1 \end{bmatrix} \end{array}$$

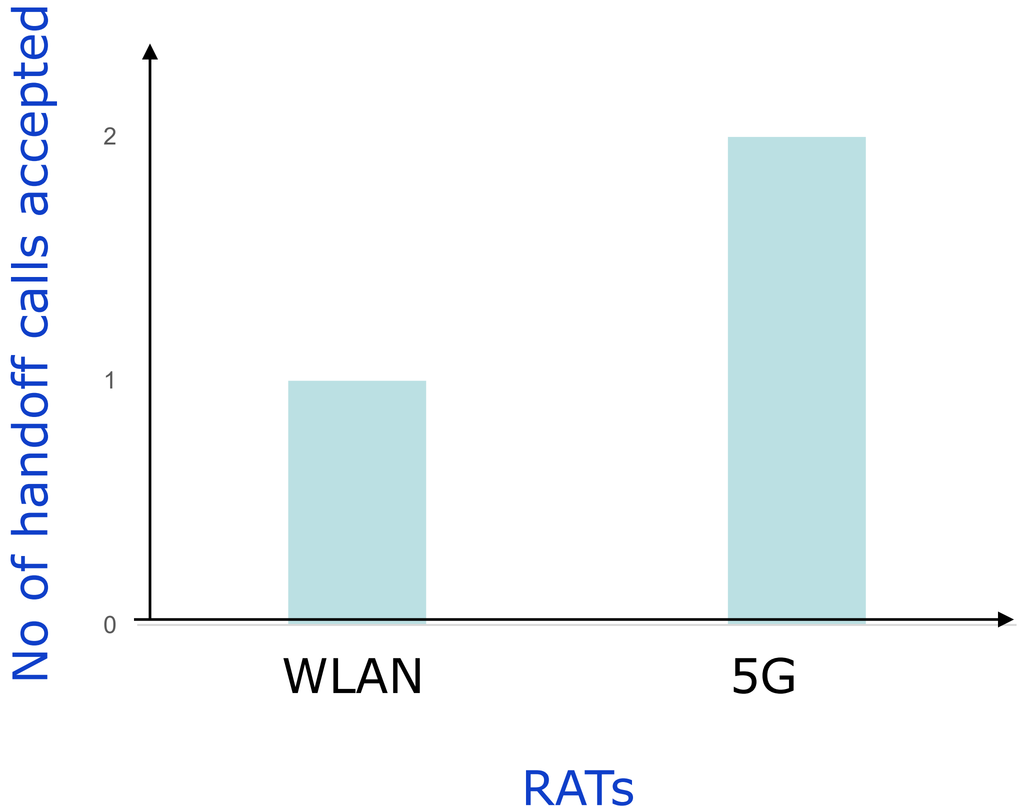
For User-3, RAT-1 score = (0.2x1) + (0.8x0.54) = 0.632

RAT-2 score = (0.2x0.2) + (0.8x1) = 0.84

Selected RAT = RAT-2 (0.84 > 0.632)

Example of RAT Selection Using SAW Technique

Distribution of handoff calls in the network



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(B) Illustration of MADM/MCDM Technique (TOPSIS)

Illustration of a procedure for making RAT-Selection decisions in a heterogeneous wireless network

(1) Specify the call to be admitted, the set of available RATs, the set of RAT-selection criteria, and the user-defined weights for RAT selection

(2) Construct the decision matrix (D)

(3) Calculate the normalised decision matrix (D')

(4) Normalise the weights assigned by the user for the class of call. (Each user would provide his/her preference information for a particular RAT for each class of calls. This preference information is specified in terms of weight.)

(5) Calculate the weighted normalized decision matrix.

(6) Determine the ideal solution (best), A* (best) and the negative ideal solution A- (worst) of H.

(7) Calculate the closeness coefficient of each of the available RATs to the ideal solution, and negative ideal solution.

(8) Select the RAT that has the highest closeness coefficient for the call.

Illustration of MADM/MCDM Technique (TOPSIS)

(1) Specify the call to be handed over, the set of available RATs, the set of RAT-selection criteria, and the user-defined weights for RAT selection

- ❑Assume there are N available RATs (RAT-1, RAT-2, …, RAT-N)
- ❑ Set of RATs, R = {RAT-1, RAT-2, …, RAT-N}
- ❑ Each RAT has X criteria (Criterion-1, Criterion-2, …, Criterion-X)
- ❑ Candidate RAT & criterion are denoted by j & u respectively
- ❑ For each class of calls, each user assigns weight w_u to each of the RAT-selection criteria.

Illustration of MADM/MCDM Technique (TOPSIS)

(2) Construct the Decision Matrix

$$
D = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array}
\begin{array}{c}
\begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\
\begin{bmatrix}
m_{11} & m_{12} & \cdots & m_{1X} \\
m_{21} & m_{22} & \cdots & m_{2X} \\
\vdots & \vdots & \cdots & \vdots \\
m_{N,1} & m_{N,2} & \cdots & m_{N,X}
\end{bmatrix}
\end{array}
$$

where

m_{11} – Criterion 1 of RAT 1

m_{1X} – Criterion X of RAT 1

m_{N1} – Criterion 1 of RAT N

m_{NX} – Criterion X of RAT N

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Illustration of MADM/MCDM Technique (TOPSIS)

(3) Calculate the normalised decision matrix (D')

$$
\mathbf{D'} = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array}
\begin{array}{c}
\begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\
\begin{bmatrix}
\overline{m}_{11} & \overline{m}_{12} & \cdots & \overline{m}_{1X} \\
\overline{m}_{21} & \overline{m}_{22} & \cdots & \overline{m}_{2X} \\
\vdots & \vdots & \cdots & \vdots \\
\overline{m}_{N,1} & \overline{m}_{N,2} & \cdots & \overline{m}_{N,X}
\end{bmatrix}
\end{array}
$$

$$
\overline{m}_{j,u} = m_{j,u} \Big/ \sqrt{\sum_{j=1}^{N} (m_{j,u})^2}\ , \ j = 1, \ldots, N \quad , u = 1, \ldots, X
$$

where $\overline{m}_{j,u}$ is the normalized performance rating of RAT, R_j on criterion, c_u .

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Illustration of MADM/MCDM Technique (TOPSIS)

(4) Calculate the Normalised Weight

- In MCDM problems, each user would provide his/her preference information for a particular RAT for each class of calls. This preference information is specified in terms of weight attached to each network criterion by the user.

- The weighing vector, W_i represents the relative importance of the criteria to user i, and it is given as:

$$W = \{ w_1 \quad w_2 \quad \cdots \quad w_X \}$$

The weighing vector is normalized as follows:

$$\overline{W} = \{ \overline{w}_1 \quad \overline{w}_2 \quad \cdots \quad \overline{w}_X \}$$

$$\overline{w}_v = \frac{w_v}{\sum_{u=1}^{X} w_u} \qquad v = 1, 2, \cdots, X$$

- For example, a 10-point weigth scale = {0, 1,2,3,4,5,6,7,8,9}

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Illustration of MADM/MCDM Technique (TOPSIS)

(5) Calculate the weighted normalized decision matrix.

$$H = \begin{array}{c} \\ R_1 \\ R_2 \\ \vdots \\ R_N \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_X \end{array} \\ \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1X} \\ h_{21} & h_{22} & \cdots & h_{2X} \\ \vdots & \vdots & \cdots & \vdots \\ h_{N,1} & h_{N,2} & \cdots & h_{N,X} \end{bmatrix} \end{array}$$

$$h_{j,u} = \mathrm{w}_{\mathrm{u}} * \overline{m}_{j,u} \quad \forall\ j \in \{1, \ldots, \mathrm{N}\}, u \in \{1, \ldots, X\}$$

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Illustration of MADM/MCDM Technique (TOPSIS)

(6) Determine the ideal solution (best), A* (best) and the negative ideal solution A- (worst) of H.

$$A^* = [h_1^*, h_2^*, \ldots, h^*]$$

$$A^* = \{(\max_{j \in R} h_{ju} \mid u \in C'), (\min_{j \in R} h_{ju} \mid u \in C'')\}$$

$$A^- = [h_1^-, h_2^-, \ldots, h^-]$$

$$A^- = \{(\min_{j \in R} h_{ju} \mid u \in C'), (\max_{j \in R} h_{j_u} \mid u \in C'')\}$$

where C' is the set of benefit criteria, and C'' is the set of negative criteria. Note that $C = C' + C''$.

Illustration of MADM/MCDM Technique (TOPSIS)

(7) Calculate the closeness coefficient of each of the available RATs to the ideal solution, and negative ideal solution.

- The basic principle of TOPSIS is that the selected RAT should have the shortest distance from the ideal solution and the farthest distance from the negative ideal solution.

$$d_j^* = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_u^*)^2} \ , \ j = 1,\ldots,N$$

$$d_j^- = \sqrt{\sum_{u=1}^{X} (h_{j,u} - h_u^-)^2} \ , \ j = 1,\ldots,N$$

The closeness coefficient of RAT, denoted as f^j is obtained as:

$$f^j = \frac{d_j^-}{d_j^* + d_j^-}, \quad \forall \ j = 1,2,\ldots,N$$

Illustration of MADM/MCDM Technique (TOPSIS)

(8) Select the RAT that has the highest closeness coefficient for the call.

Load Balancing in Wireless Networks

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Load-Balancing

- Load balancing in wireless communication is the process of distributing calls from subscribers among different cells of a wireless network or among different wireless access networks with the aim to achieve increased radio resource utilization in these various networks

- Load balancing can be triggered when certain threshold in resource utilisation is exceeded in a particular cell or RAT

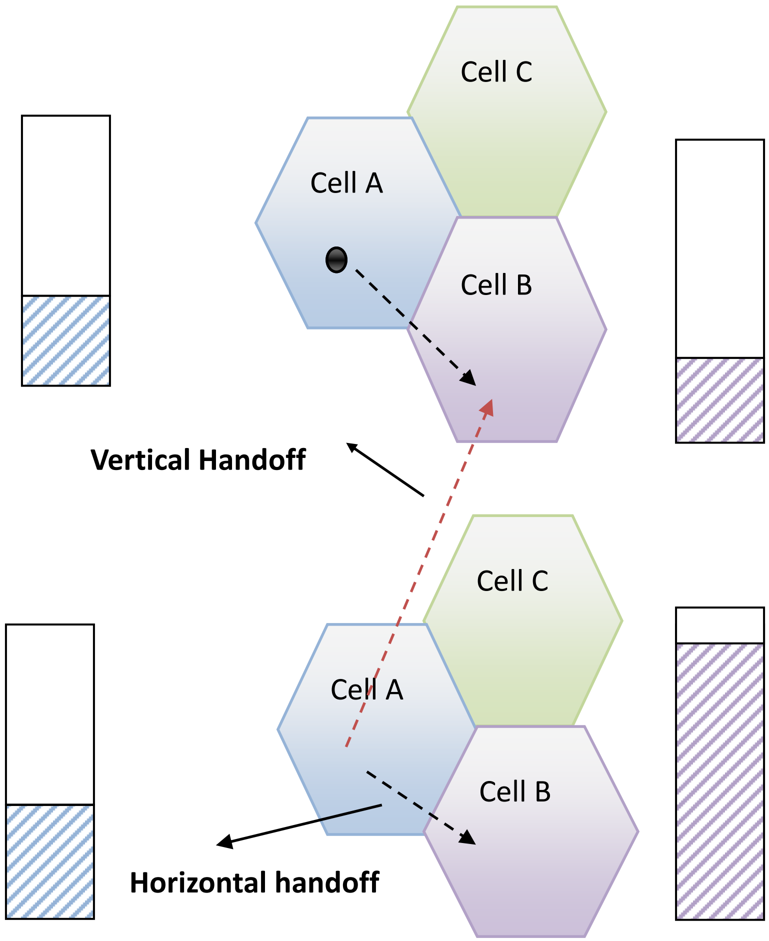
Motivations for Load Balancing in heterogeneous wireless networks

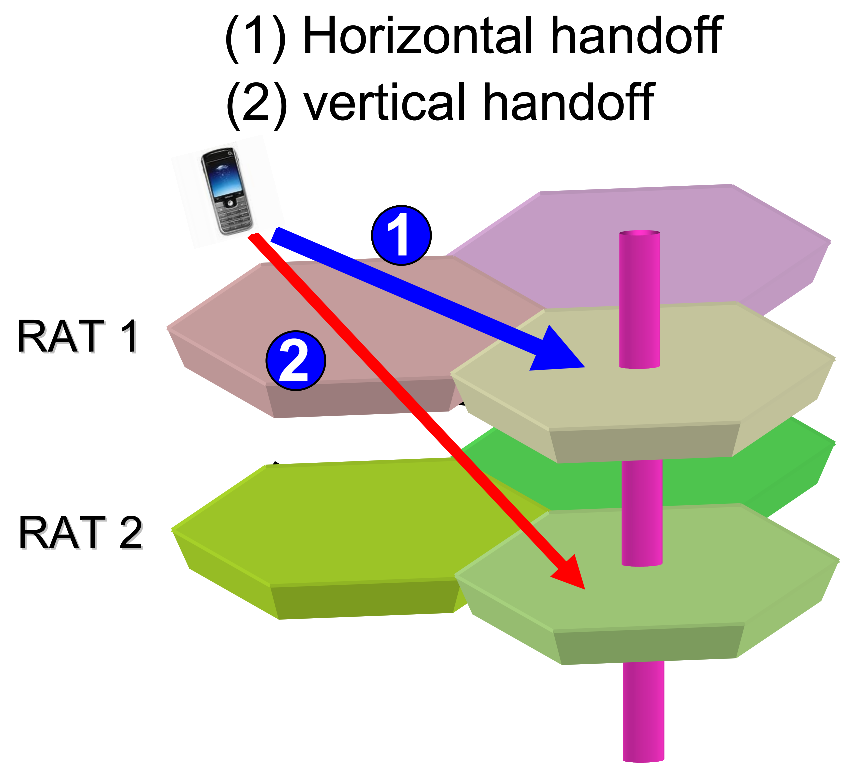
(1) Reduction of Frequency of vertical handoffs

- One of the motivations of load balancing is to reduce the frequency of handoff
- In wireless communication networks, it is necessary to reduce the number of vertical handoff as much as possible

Motivation for Load Balancing in Heterogeneous Network

(1) Reduction in frequency of vertical handoffs through load balancing





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Motivation for Load Balancing in Heterogeneous Networks

(2) Improvement of Resource Utilization

- Load balancing mechanism ensures that there is a fair share of resources among different networks

(3) Improvement of Quality of Service (QoS)

- Introduction of load balancing scheme provides a congestion relief to those access networks with high density of users

- Neighbouring access networks that are lightly loaded agree to accept calls from highly loaded networks with the aim to maintain or improve network performance as well as QoS provided to the end users

Techniques for Load Balancing

Techniques for balancing traffic load in heterogeneous wireless networks can be classified as follows:

(1) forced and unforced load balancing
(2) price based and non-price based load balancing
(3) user preference based and non-user preference based
(4) call-type based (new call, handoff call, or both).

Forced and Unforced Load Balancing

- In forced based load balancing, calls (new or hand off calls) are forced to move from a particular access network mainly due to deteriorating signal strength or when network load is above a certain threshold

- In unforced load balancing, calls are not forced to move to another network but calls are moved mainly due desire to change for better performance, for instance if some users cannot access a particular network (i.e. if they are queuing for a service) they may look for other available network with better performance

Price Based and non- Price Based Load Balancing

- In price-based load balancing, service price is used to distribute the network load. The pricing mechanism gives the users incentives to make a call or not. For instance, during congestion period a high price will make some users to shorten their calls or try to move to another access network to obtain a cheaper price, hence this will evenly distribute network load during congestion period

- In non-price based load balancing, service price is not considered in making load-balancing decisions

User Preference Based or Non-user Preference Based Load Balancing

- Under user-preference based load balancing, user's preferences are first considered before calls are moved from one access network to another

- In non-user preference based load balancing, users' preferences are not considered during load balancing. Calls are moved to any available RAT without considering individual users' preferences

Load Balancing Based on Type of Call

- When load balancing is based on type of calls, only certain types of calls are used for load balancing

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!

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