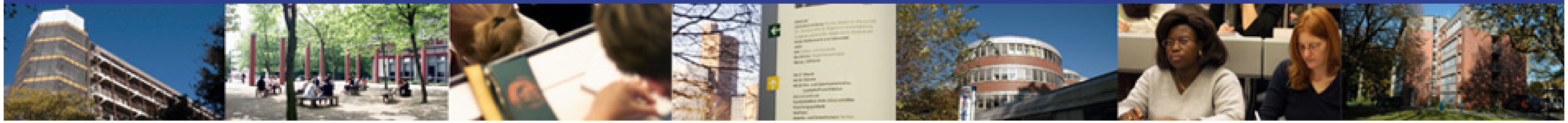

Common Radio Resource Management
- CRRM -
Theory, Architectures, Algorithms

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Germany

Outline

- Motivation
- History and Terms
- Theory
- Systematic View
- Architectures
- Algorithms
- Summary

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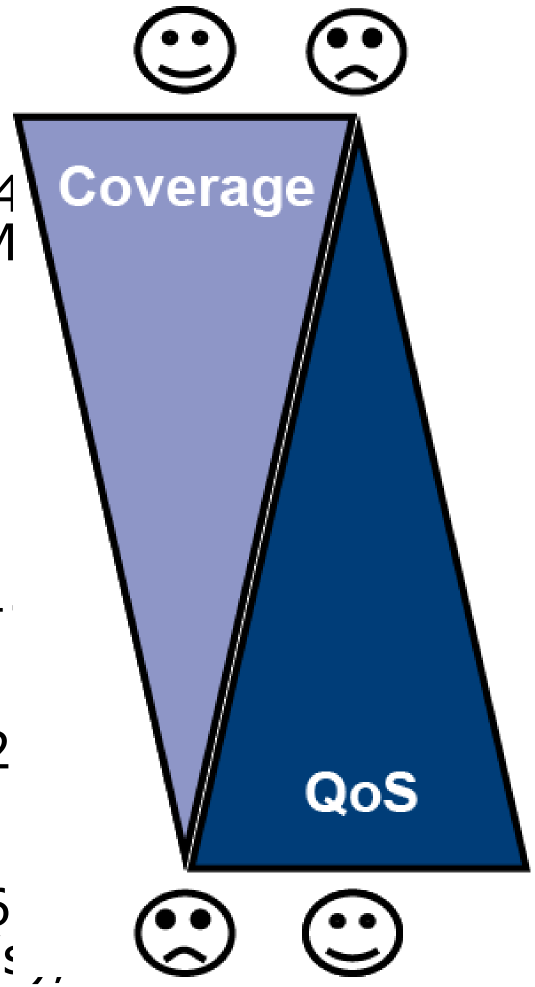
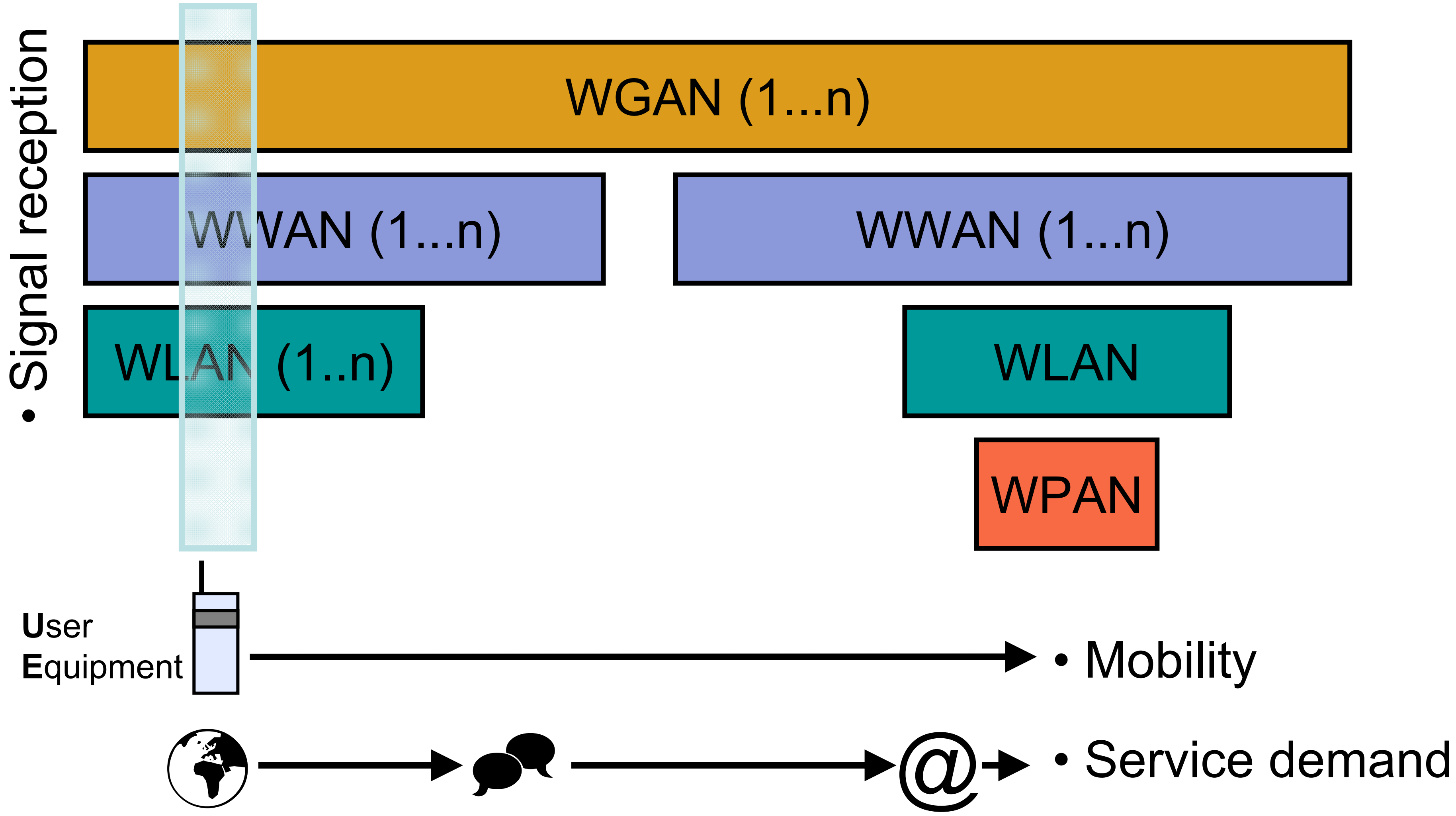
Different coexisting Radio Access Technologies

- **WGAN** - Wireless *Global* Area Network
  - Inmarsat (492 kbit/s), Thuraya (60 - 144
    Iridium (10 kbit/s), ASTRA2Connect (2 M
- **WWAN** - Wireless *Wide* Area Network
  - UMTS-HSDPA (14,4 Mbit/s),
    UMTS-LTE (326 Mbit/s - 1 Gbit/s),
    GSM-GPRS (171,2 kbit/s),
    GSM-E-GPRS (473,6 kbit/s - 1 Mbit/s),
    WiMax (109 Mbit/s - 1 Gbit/s), DVB-H (1
- **WLAN** - Wireless *Local* Area Network
  - 802.11b,n (11 - 600 Mbit/s), HIPERLAN2
- **WPAN** - Wireless *Personal* Area Network
  - Bluetooth 3 (2,2 - 480 Mbit/s) , IrDA (16
    DECT (552 kbit/s), WirelessHD (25 Gbit/
    W-USB (480 Mbit/s)

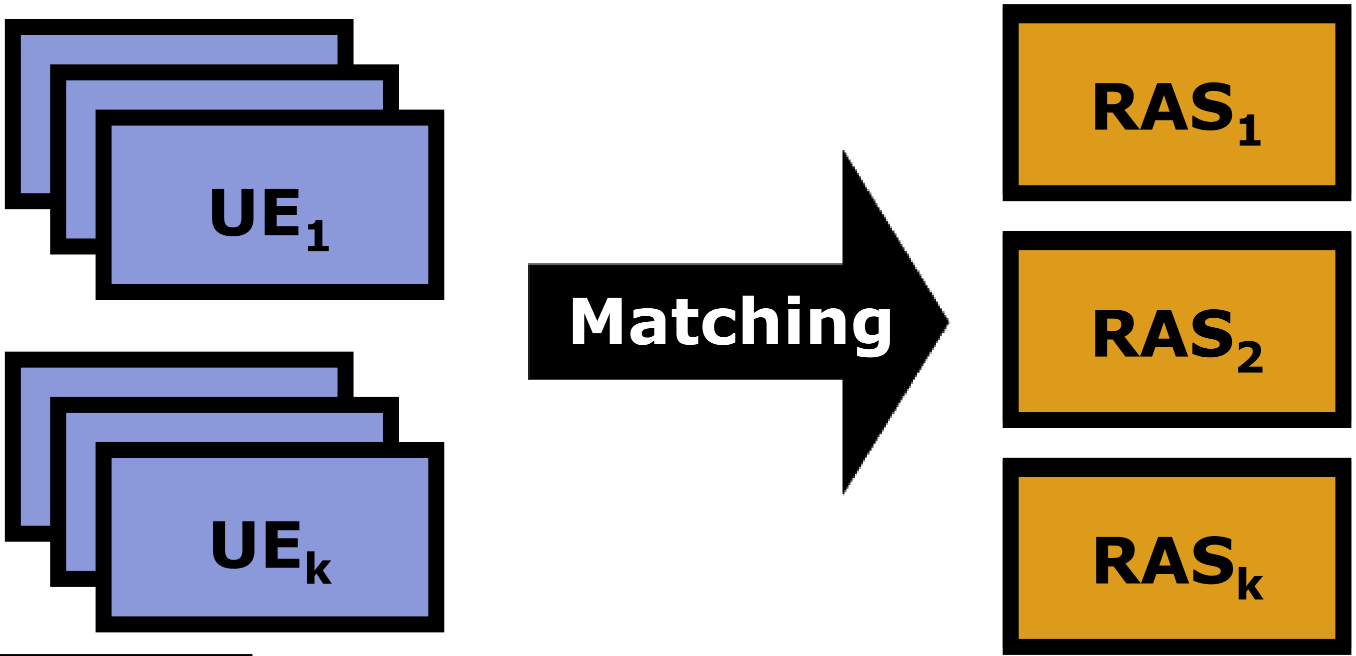


UE in a Changing Environment



CRRM Problem

- **Set of UE**
  - QoS demand
  - Resource consumption
  - Supported RAT/Provider
  - Available RAS…
- **Set of RAS**
  - QoS offered
  - Availabe Resources
  - Coverage
  - RAT/Provider…



CRRM Goal

- **Goal:** optimal distribution of service sessions (matching) to available radio access systems
  - Satisfied users, minimal costs
- **Possible actions to meet this goal:**
  - Handover (intrasystem, intersystem)
  - Adapt offered QoS
  - Change RRM-properties (e.g. allocate additional frequencies)
- **Complex task due to dynamics in the system and many influencing factors**
  - Properties of wireless system and user equipment

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Always Best Connected

- **Gustafsson** and **Jonsson** (2003)
- ABC-concept defines the goal
  - **User centered, task oriented**
  - **Best available access network/device at any point in time**
  - Wired or wireless
- Components
  - Content adaption
  - Profile handling
  - Mobility management
  - AAA support
  - Access selection
  - Access discovery

Cognitive Radio / self-x

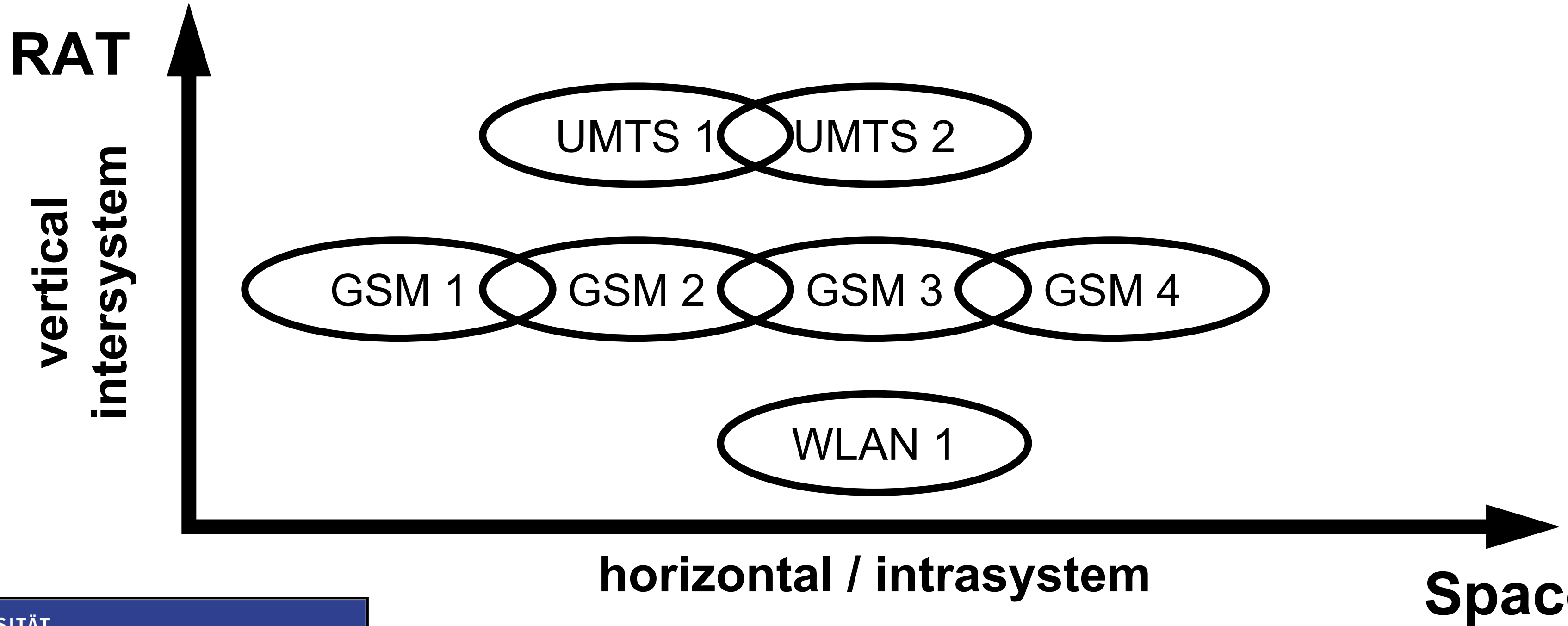
- **Mitola** and **Maguire** (1999)
- Based on Software Defined Radio (SDR)
- Vision of a complete a.i. network
  - Knowledge base
  - Model based reasoning
  - Observe, learn and plan
  - Interaction -> **Chess Game** over radio resources
- Self-x (management, configuration, preservation)
- EU-projects:
  ARAGORN (ISM-band)
  E^3 (WLAN/WWAN)

CRRM – JRRM – MRRM – MxRRM

- EU - IST – research framework
  - EVEREST, AROMA, AN, E2R…
    - Common Radio Resource Management
    - Joint RRM
    - Multi RRM
    - Multi Standard RRM
- **Focus on WWAN technologies**
  - Infrastructure based networks
  - WLAN is also considered
- **Emphasizes multiobjective optimization**
  - Addition to existing radio resource management
  - Subset of cognitive radio approach
- Joint Call Admission Control – JCAC
  - Emphasizes admission control and handoffs as a subject to multiobjective optimization

Handover/Handoff Types

- **IEEE 802.21:** vertical, horizontal handoff
  - Term mostly used in Asia, America
- **3GPP:** intersystem, intrasystem handover
  - Term mostly used in Europe, Africa



Different Terms, one Goal

- CRRM
- JRRM
- MRRM
- MxRRM
- JCAC
- Vertical Handover Control
- Cognitive Radio / self-x
- …
- **Always Best Connected!**

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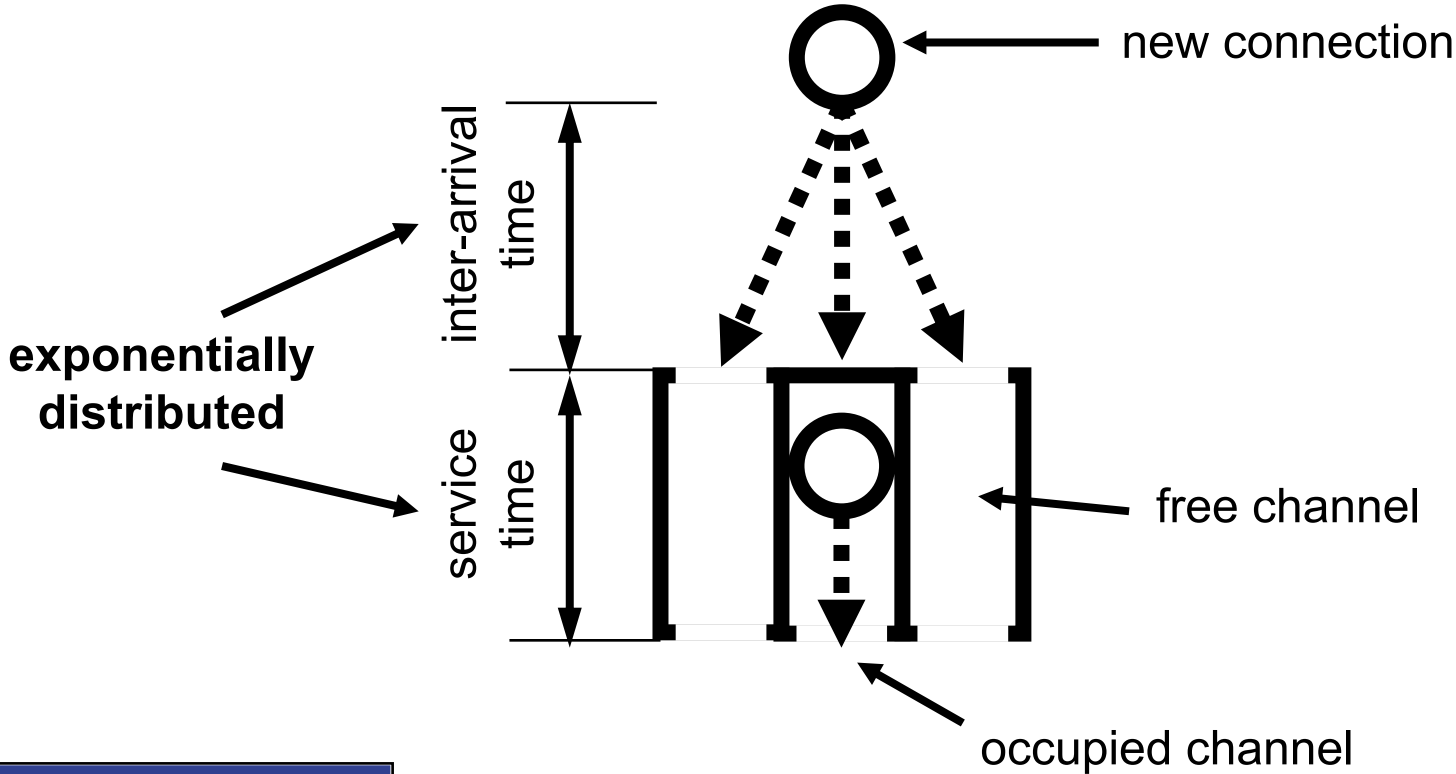
What can CRRM achieve?

- **Trunking efficiency gain**
- **Service assignment gain**

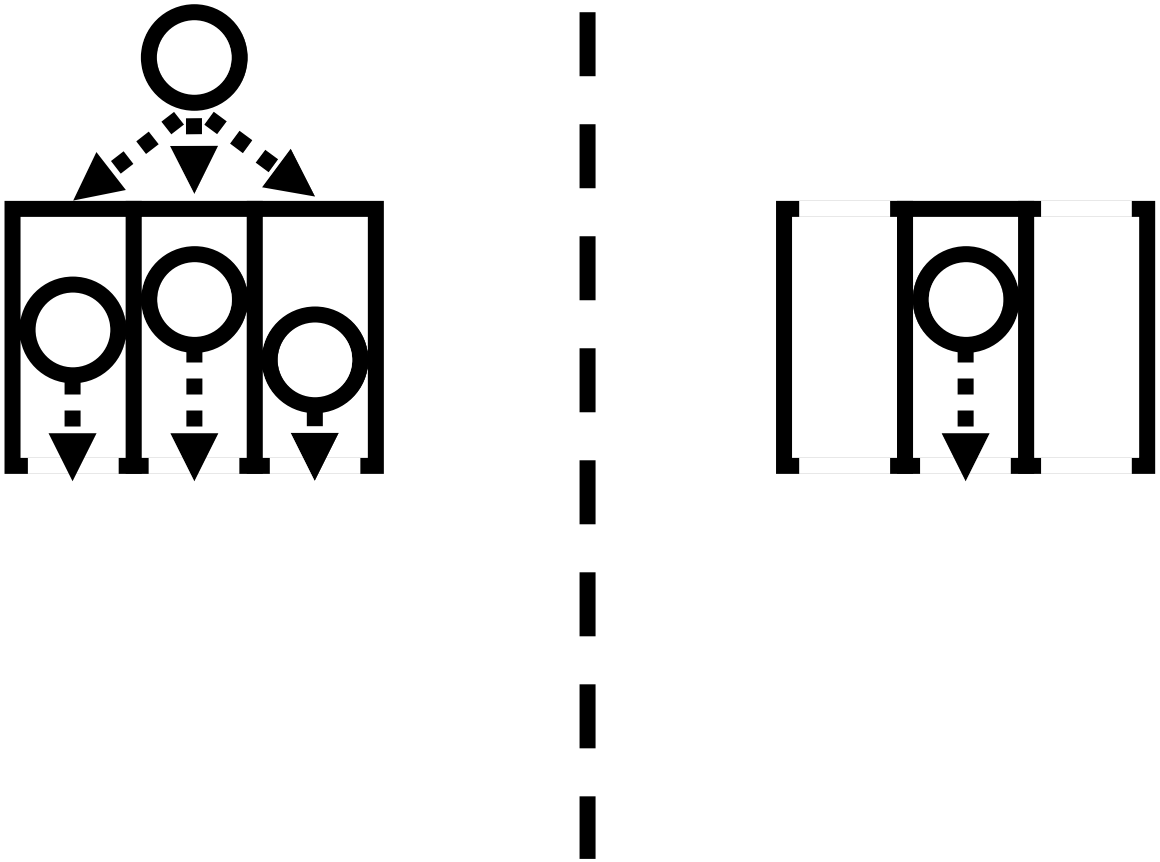
Trunking Efficiency Gain (1)

- Agner Krarup **Erlang** (1917)
  - **M/M/m/m** or M/M/m/0



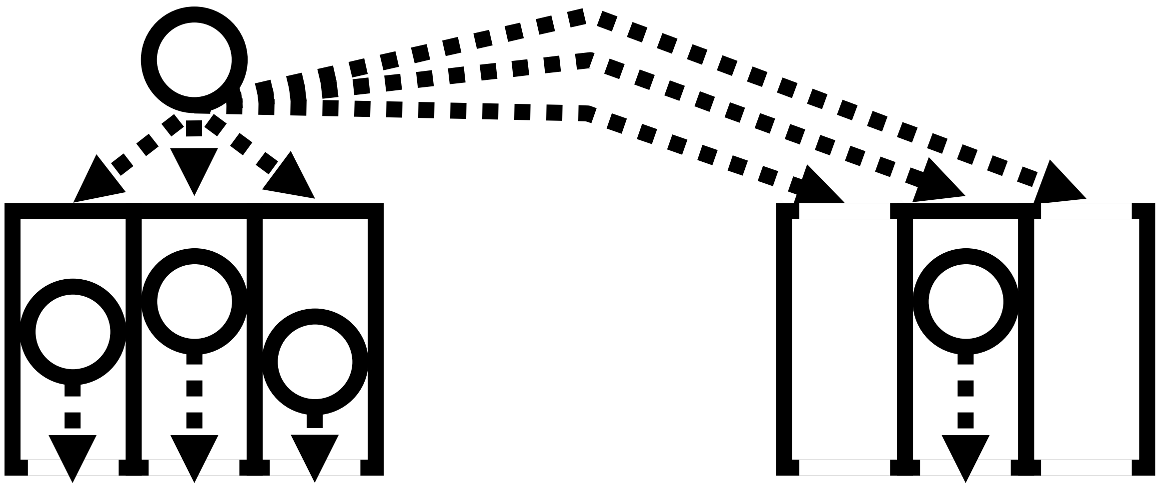
Trunking Efficiency Gain (2)

- Blocking situation in separate system



Trunking Efficiency Gain (3)

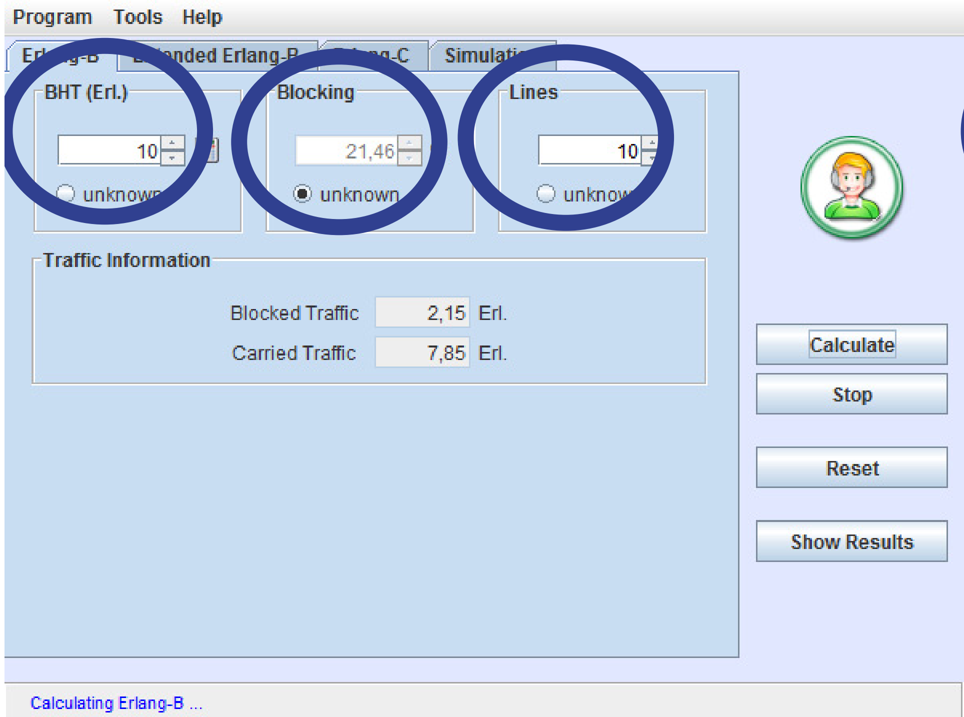
- No blocking situation in joint system

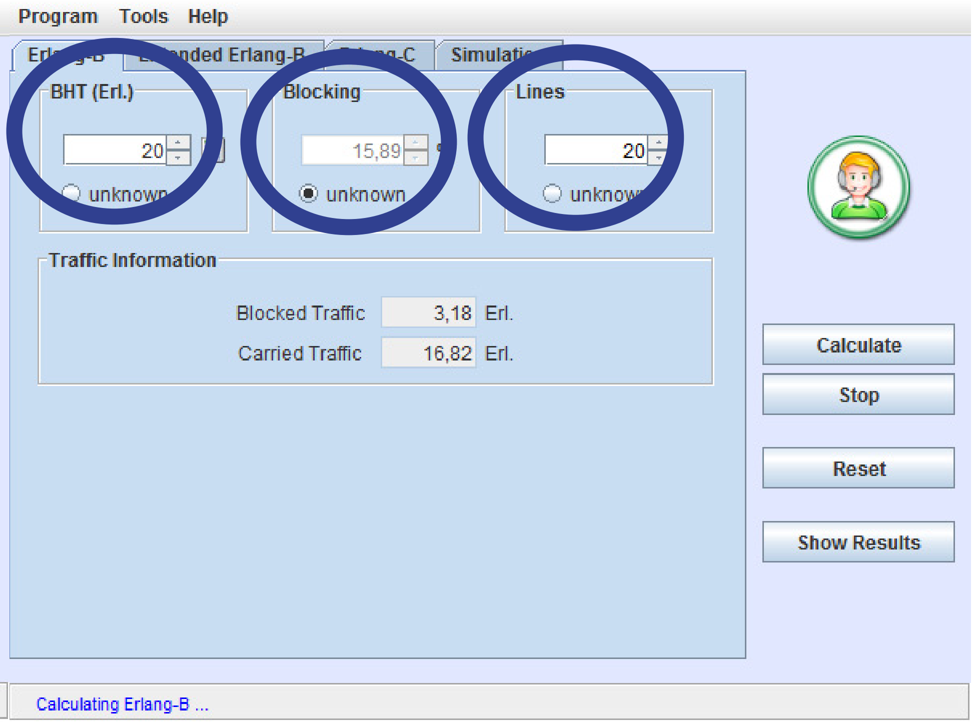


- Probability distribution of service/arrival times lead to lower blocking probabilities
  - Even for doubled offered traffic at doubled number of channels

Trunking Efficiency Gain (4)

- Example: Call Center Toolkit
  - http://sysmod.icb.uni-due.de/index.php?id=cct

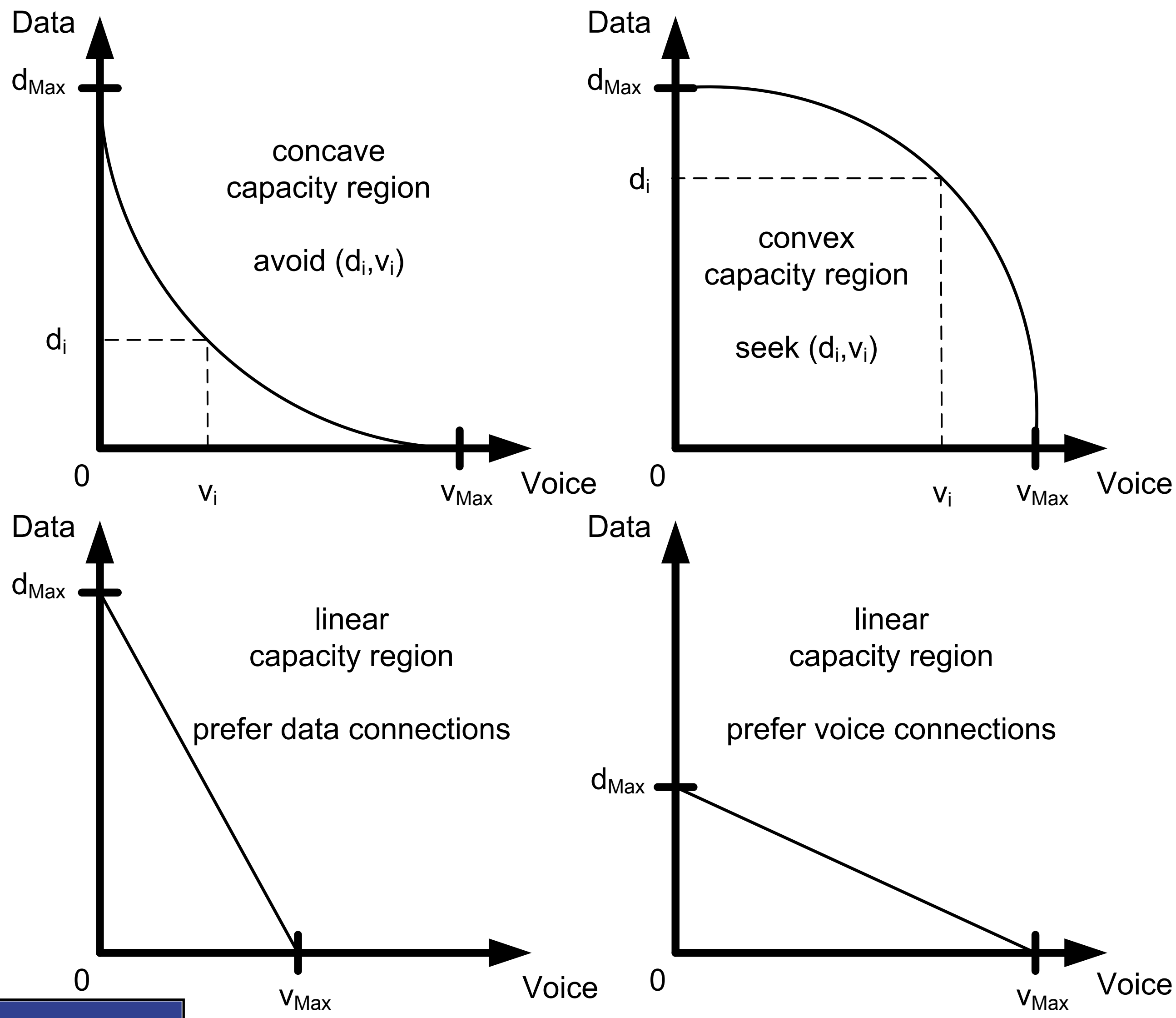




Service Assignment Gain (1)

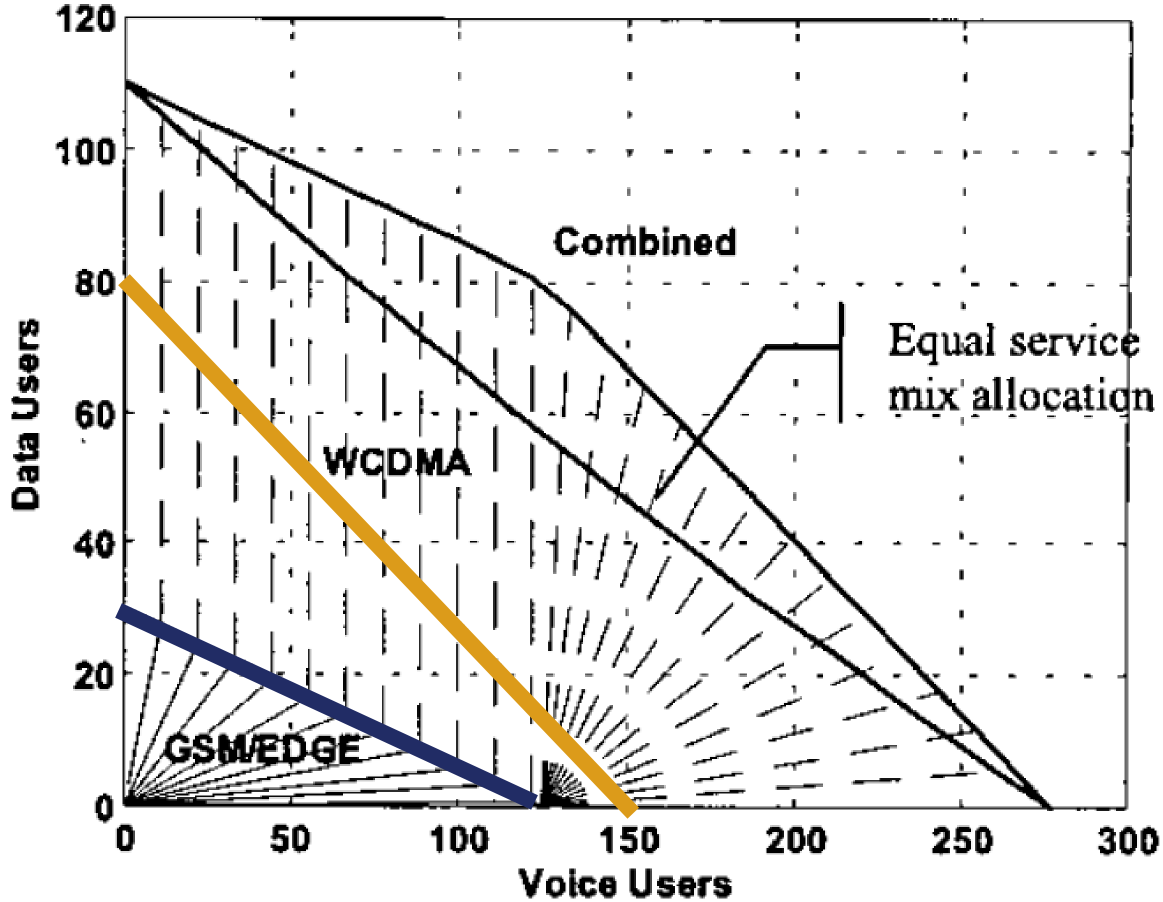
- Anders **Furuskär** (2002)
- Different systems – different capacity for various service types
- **Choose the best suitable system for the services**
- Leads to a **capacity gain additional to trunking gain**

Service Assignment Gain (2)



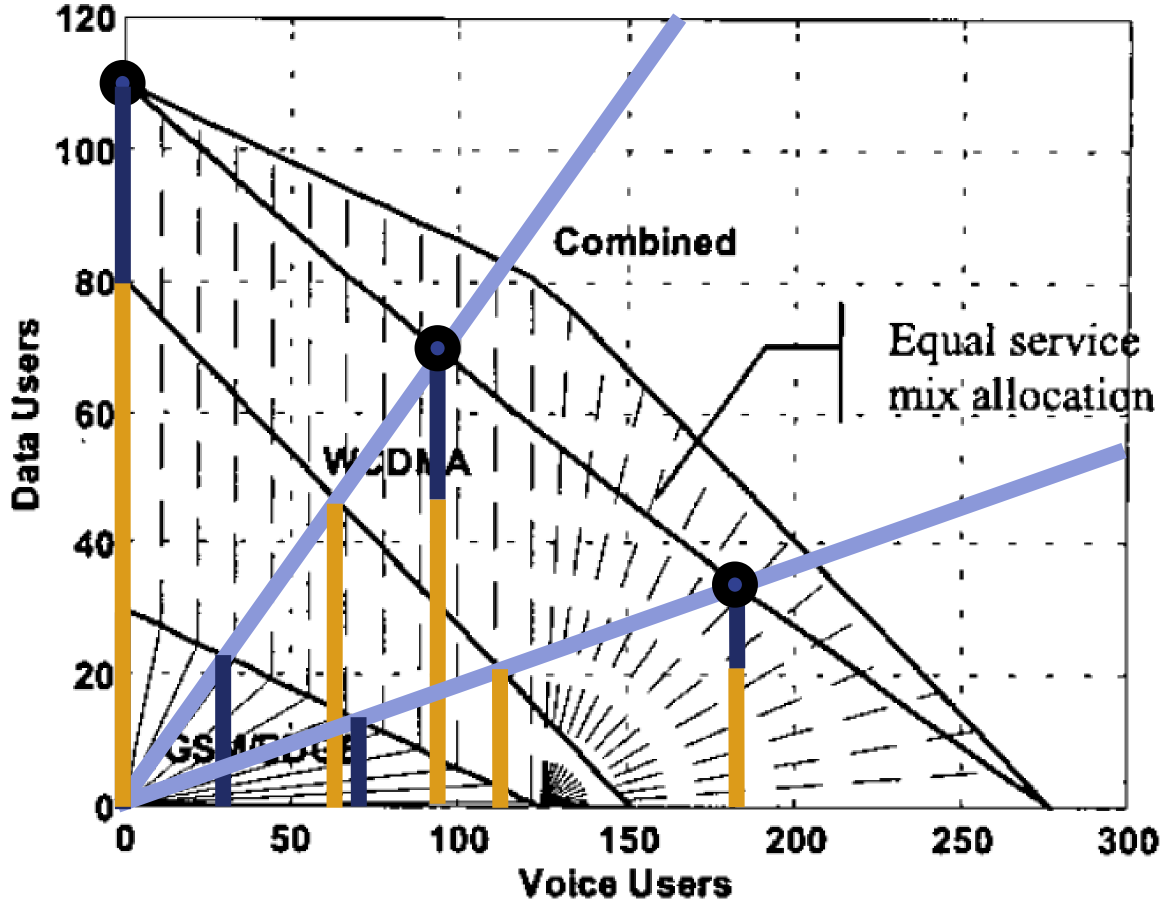
Service Assignment Gain (3)

- Capacity surfaces of GSM/EDGE & WCDMA



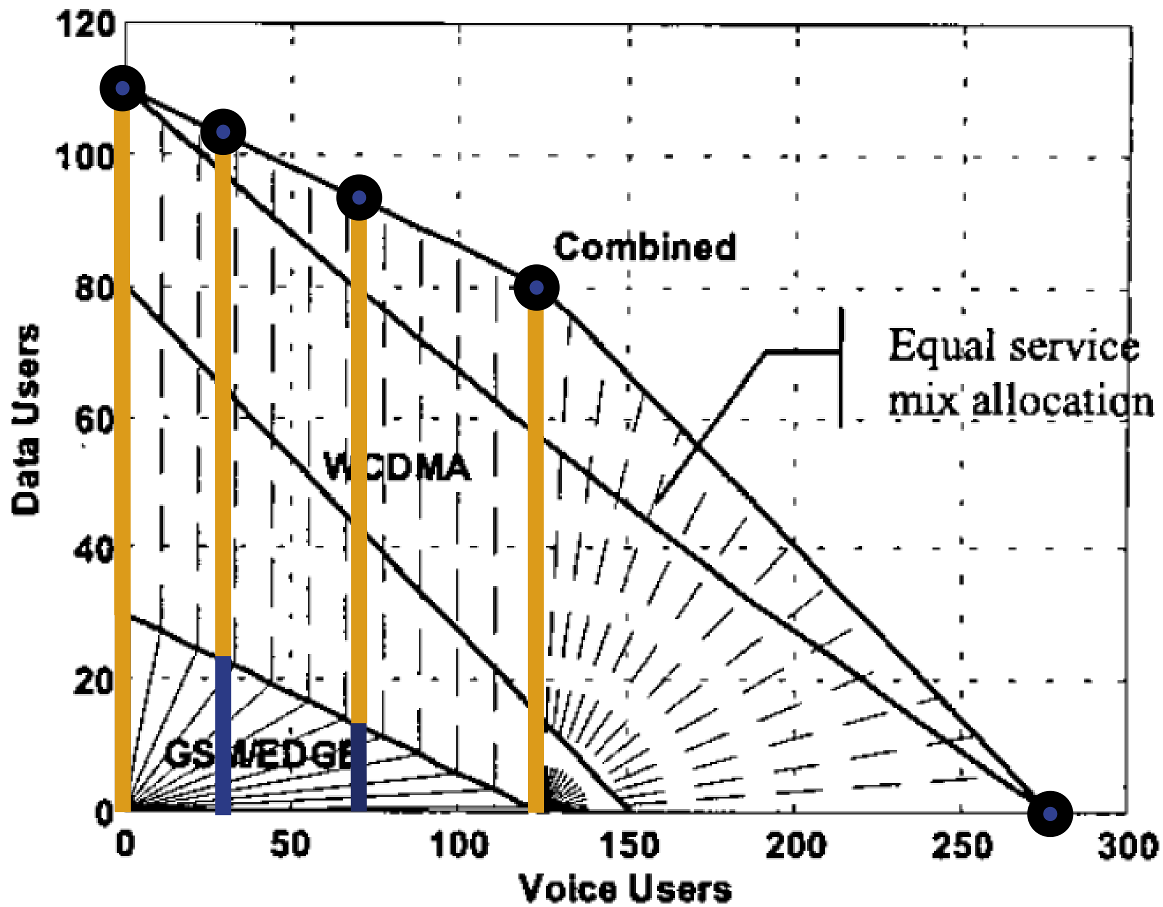
Service Assignment Gain (4)

- Equal service mix allocation



Service Assignment Gain (5)

- Service suitability based allocation



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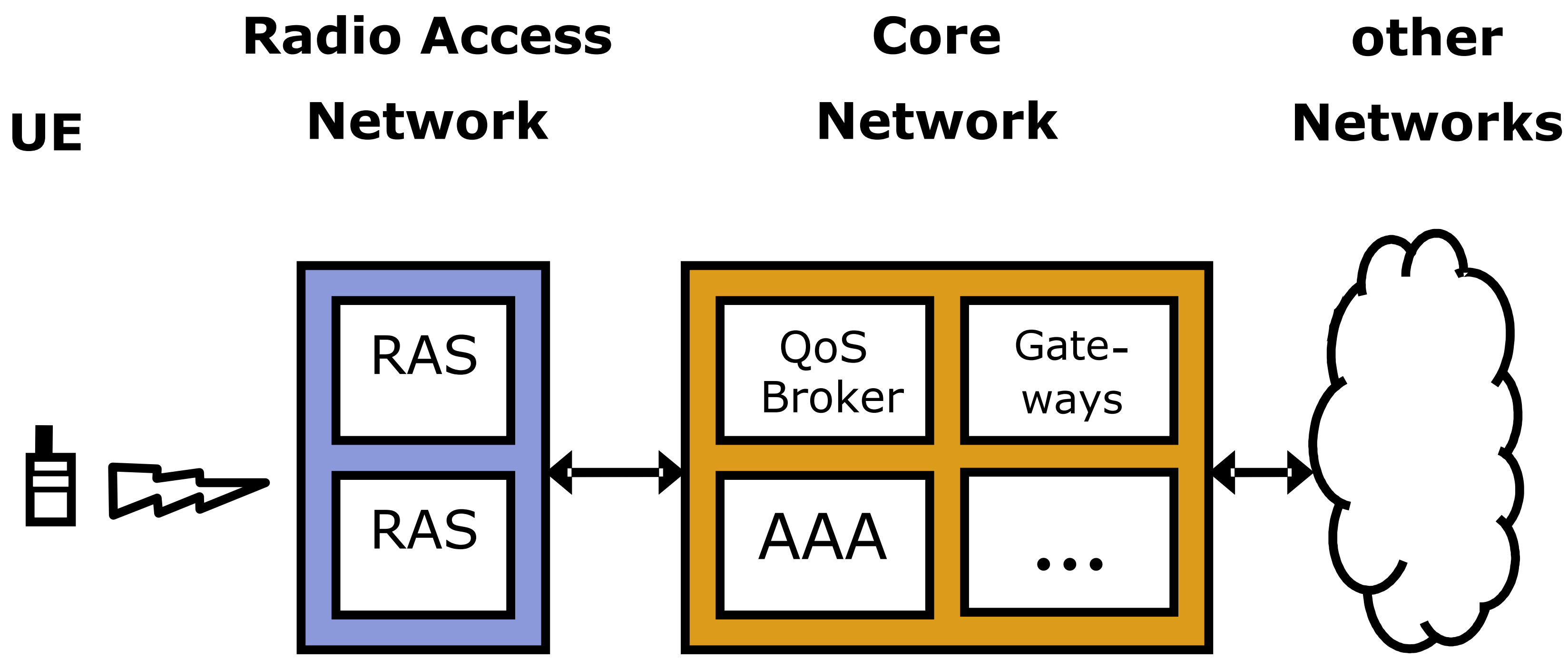
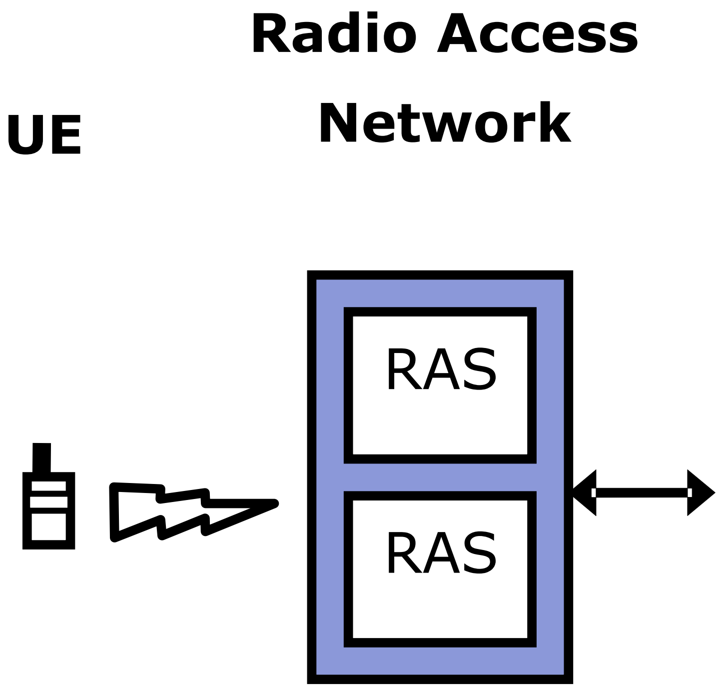
Common RAT Architecture



Common RAT Architecture

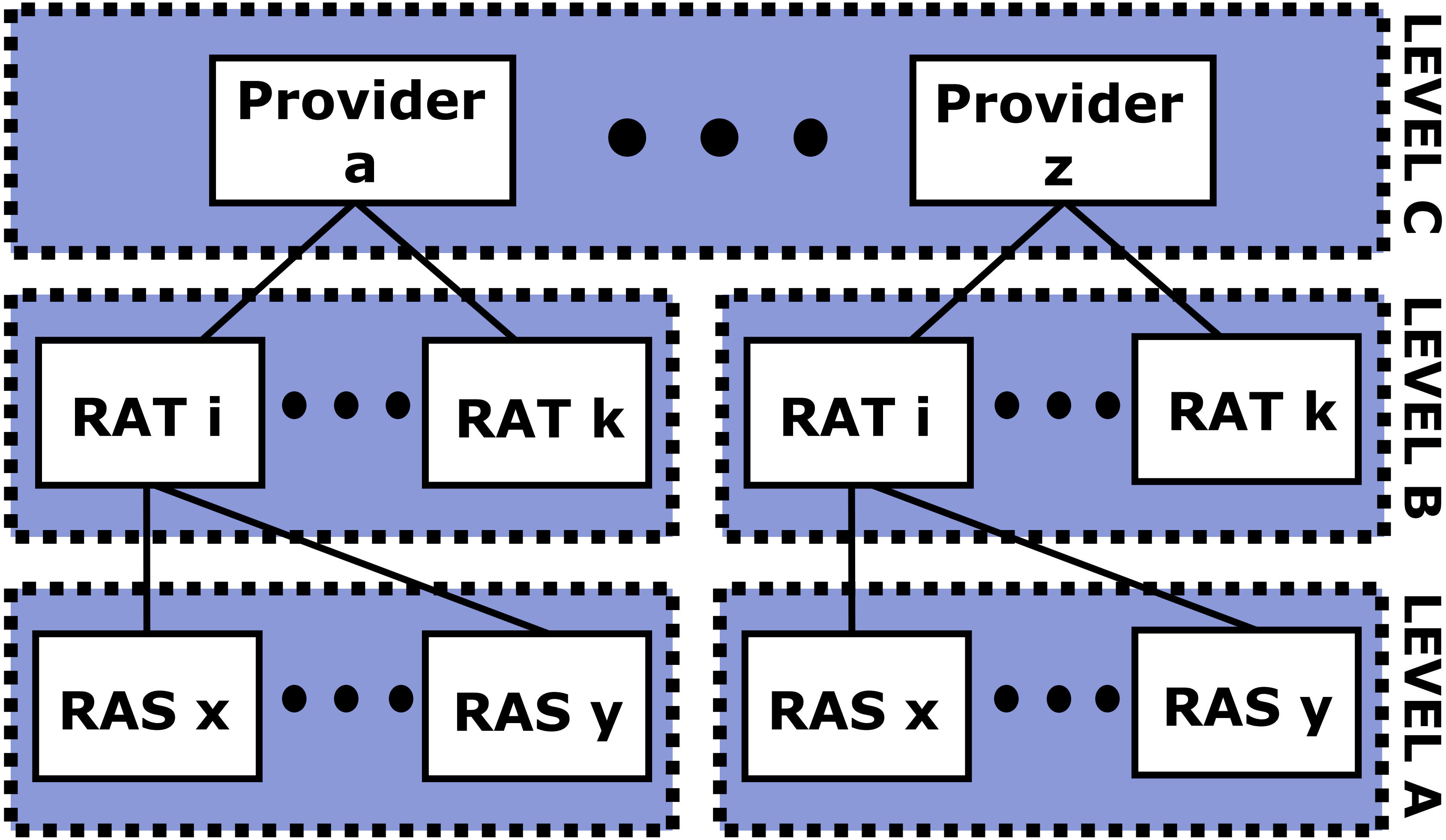


Assumption:

Core Network supports RAS features

RAS is bottleneck due to unreliable wireless links

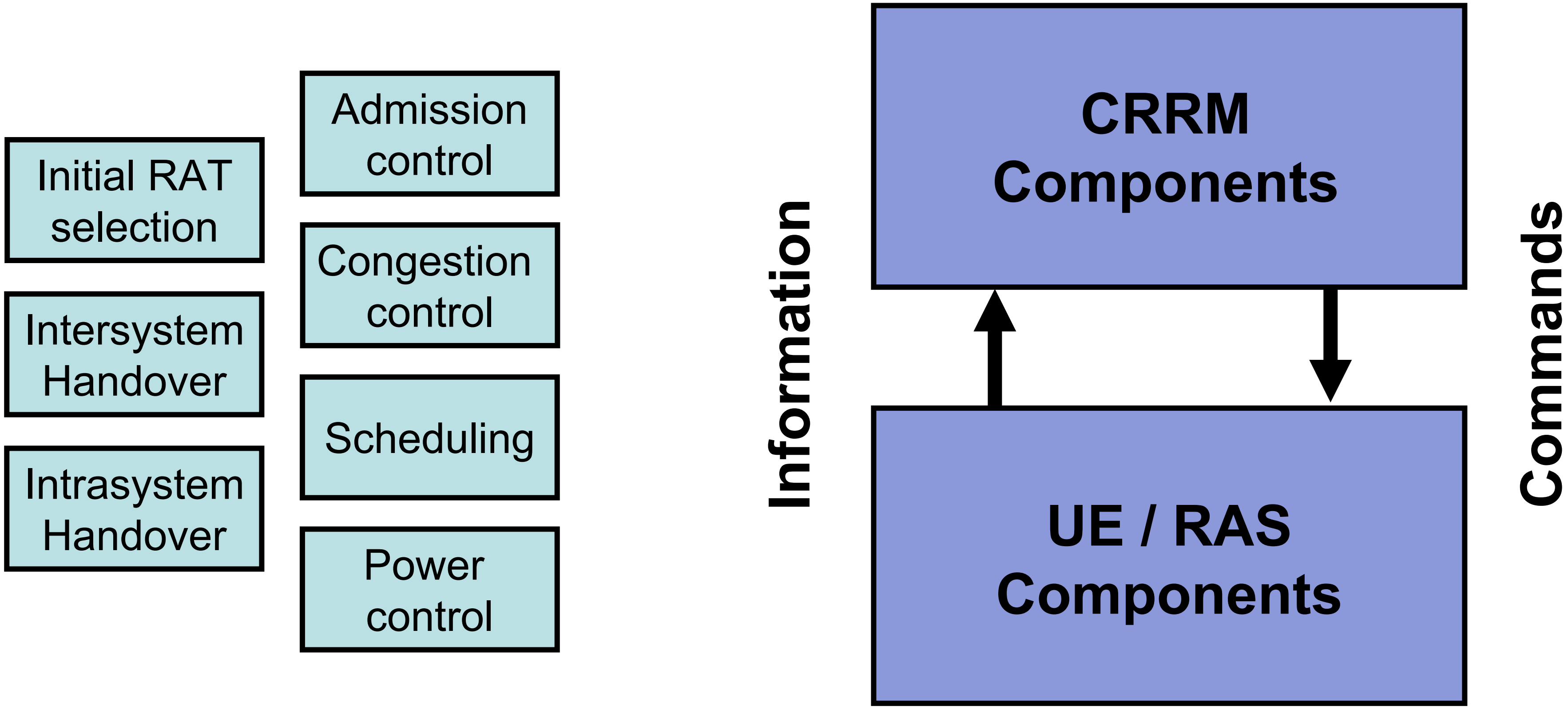
Different CRRM System Boundary Levels



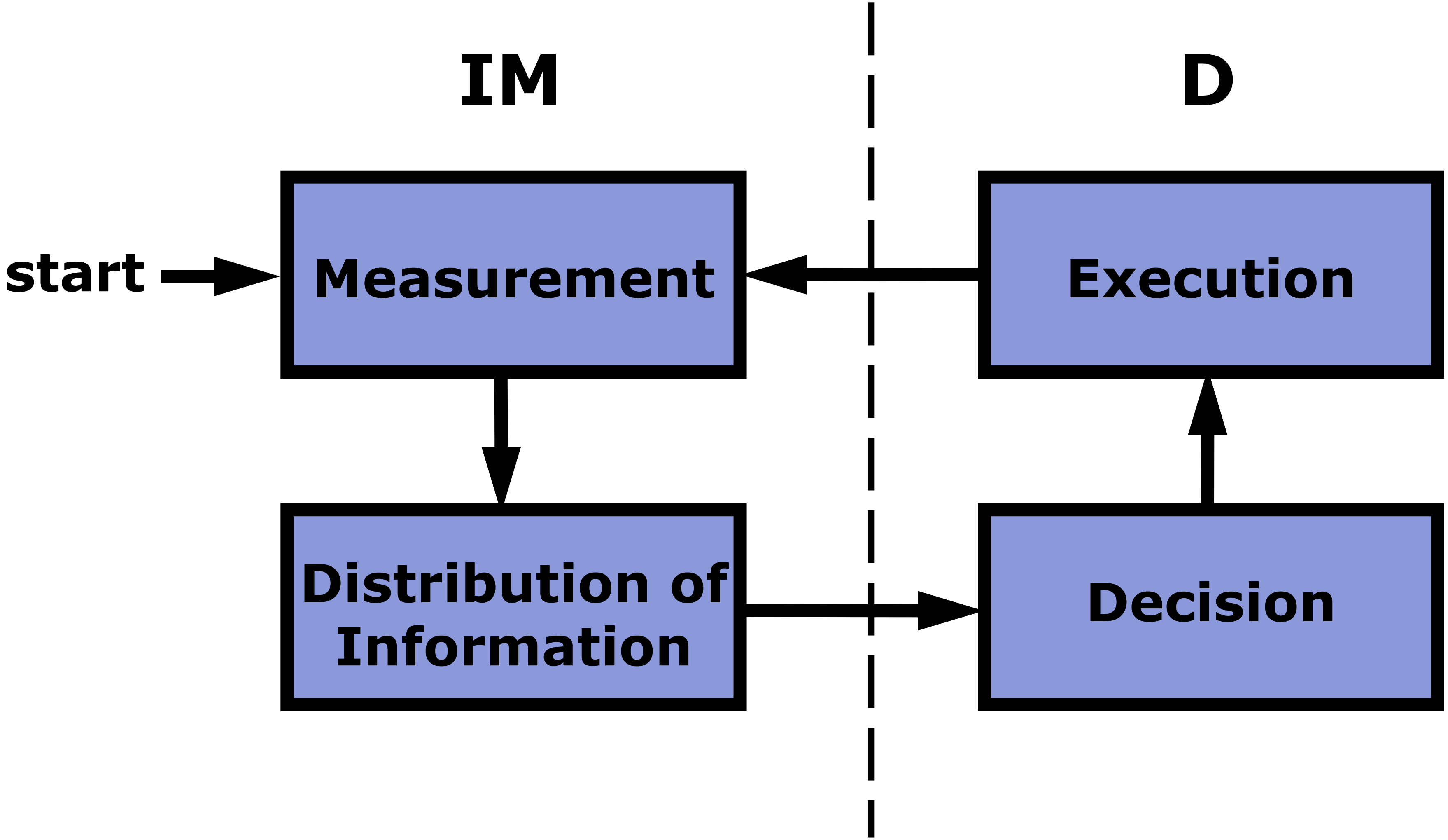
Definition of CRRM Integration Level

Tasks

Task assignment



CRRM Control Loop



Categorization of CRRM algorithms

- Close relationship to Load Sharing Algorithms
- Categories are:
  - System model
  - Transfer model
  - Information distribution model
  - Coordination model
  - Time horizon
  - Stability control
  - Adaptivity

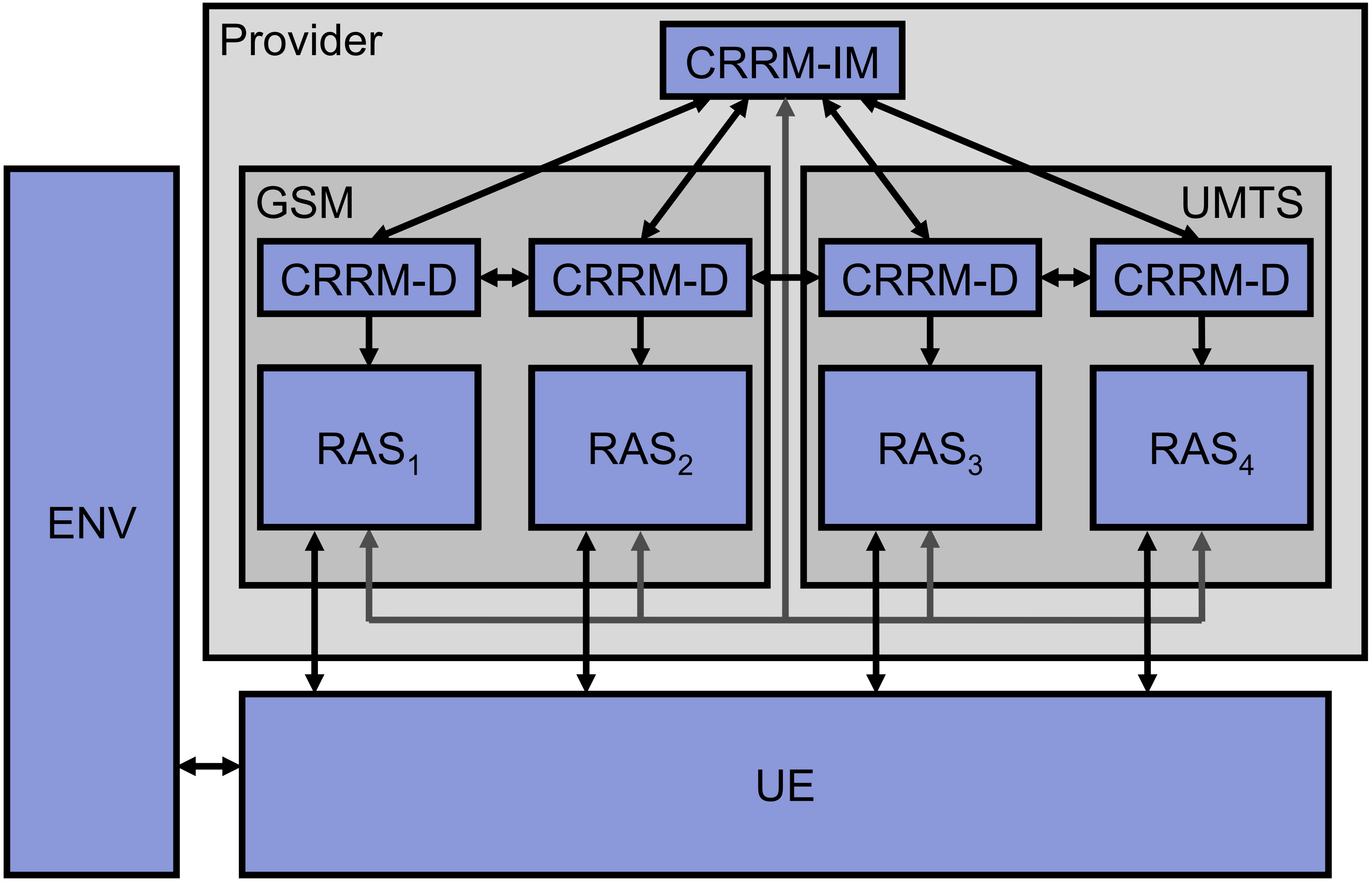
CRRM – Manifold Options

- Information management (**IM**) and decision (**D**) model
  - Level A (RAS), Level B (RAT), Level C (Provider)
    - Network initiated (NI), Mobile initiated (MI)
  - Integration levels
    - High scale, medium scale, low scale
  - System structure
    - Centralized, hierarchical, decentralized

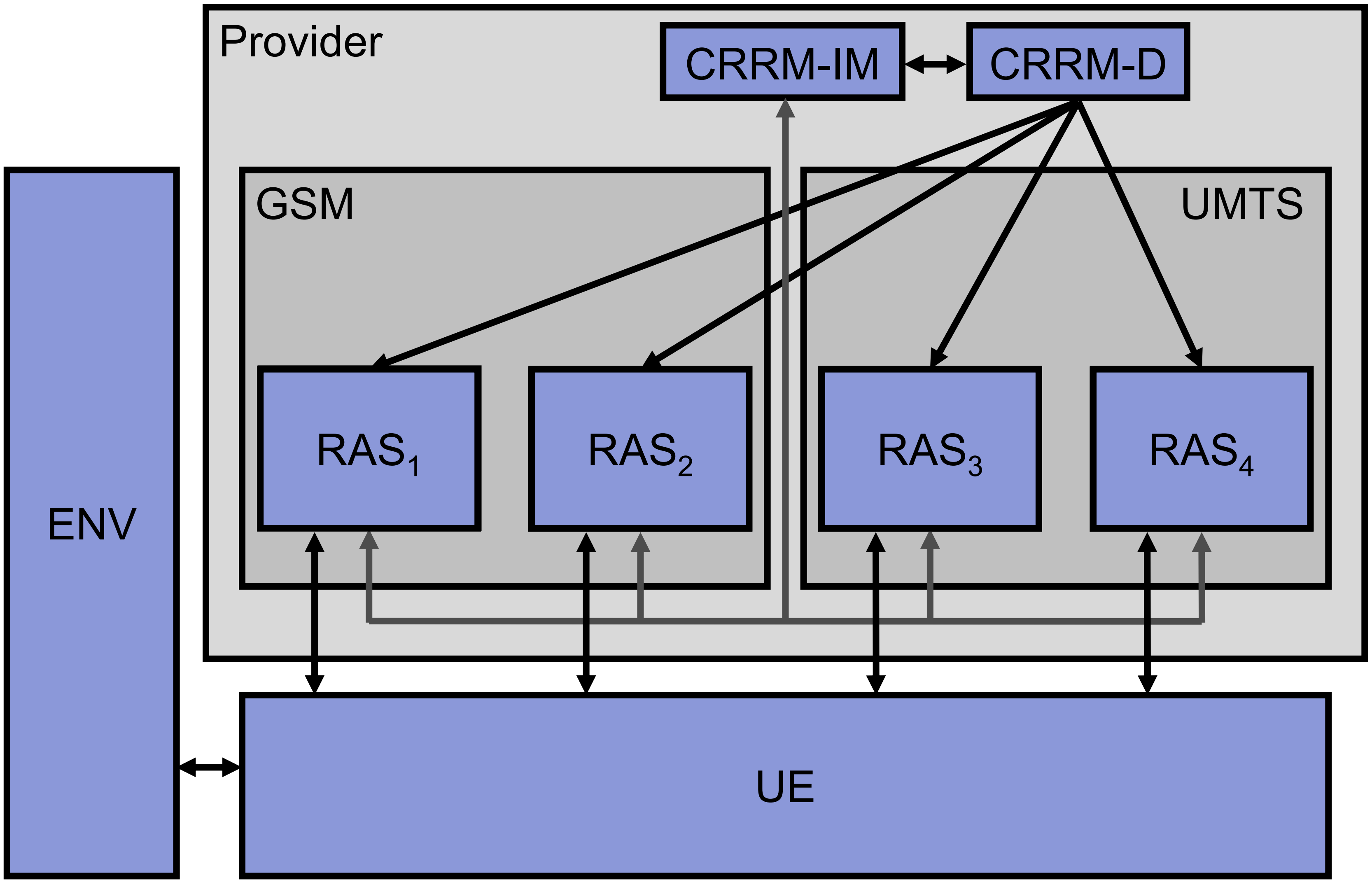
!

- Different **time horizons**
- Different **amounts of information**
  - Transferred
  - Usable

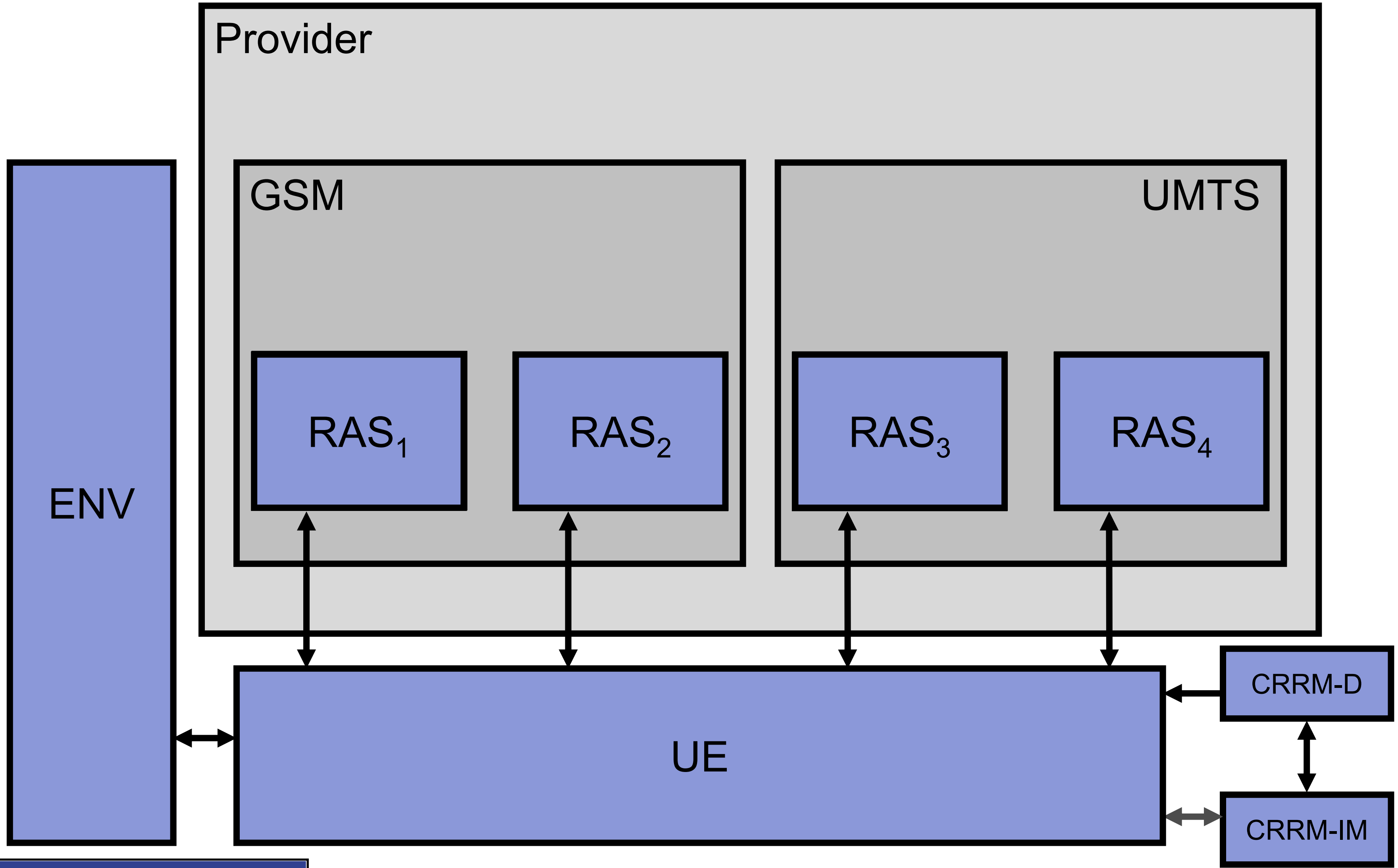
Level B Scenario Example – de/centralized NI-CRRM



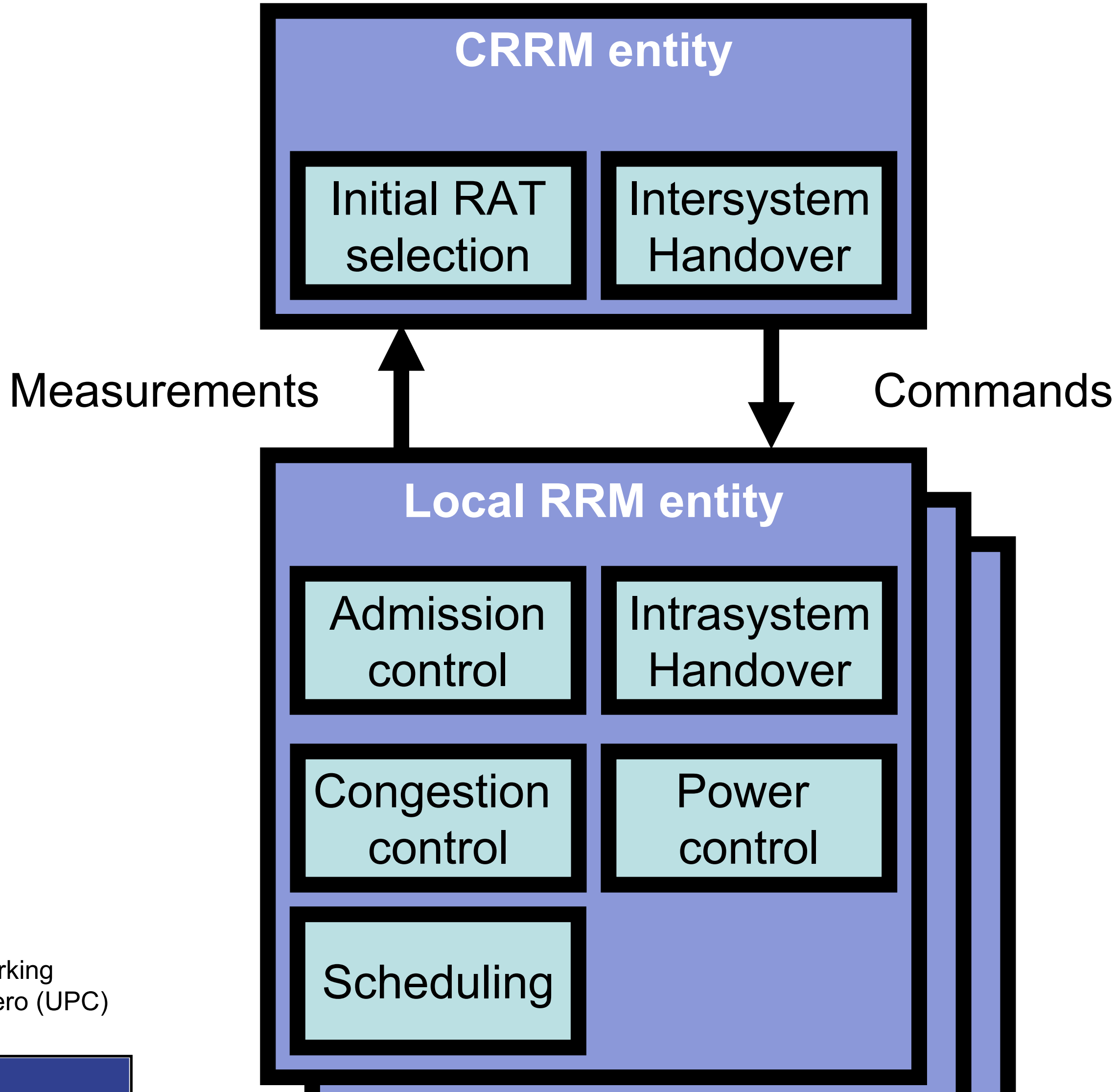
Level B Scenario Example – centralized NI-CRRM



Level B Scenario Example – decentralized MI-CRRM

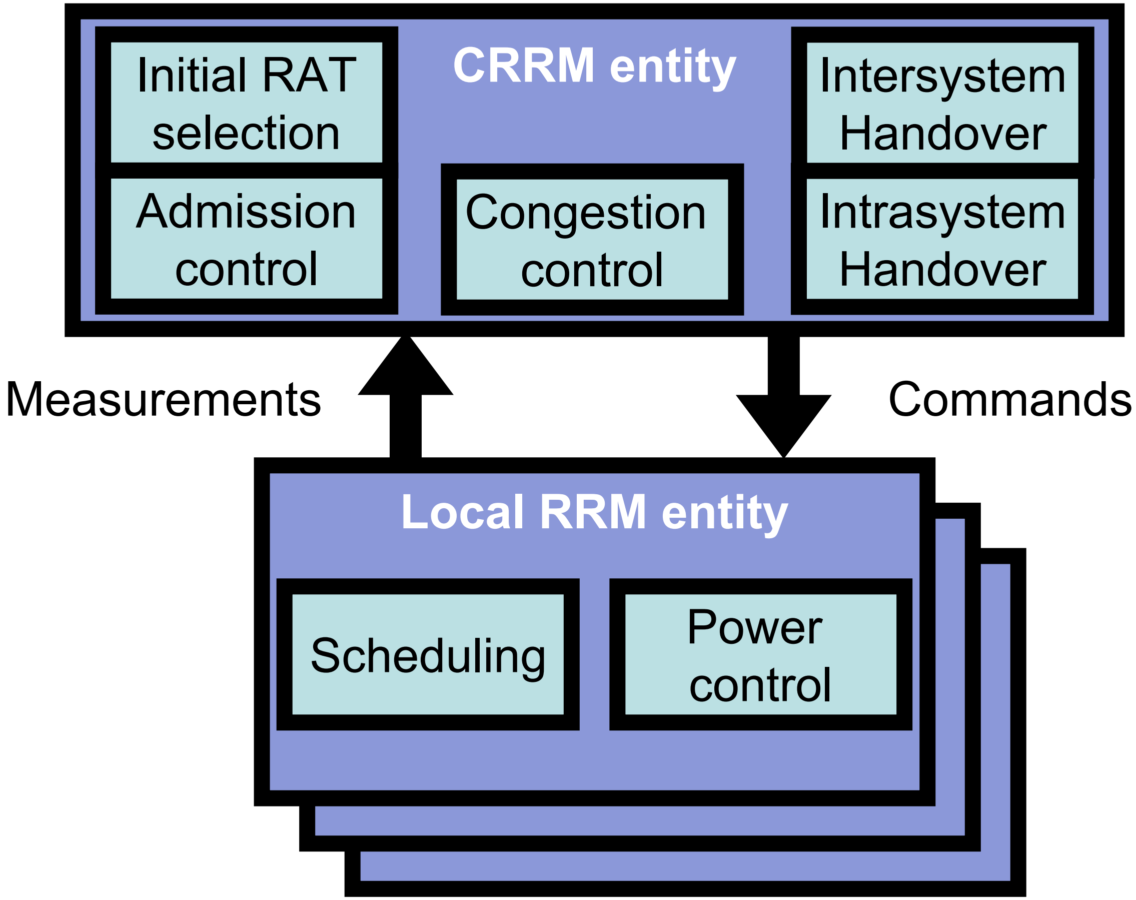


Low Scale Integration Level

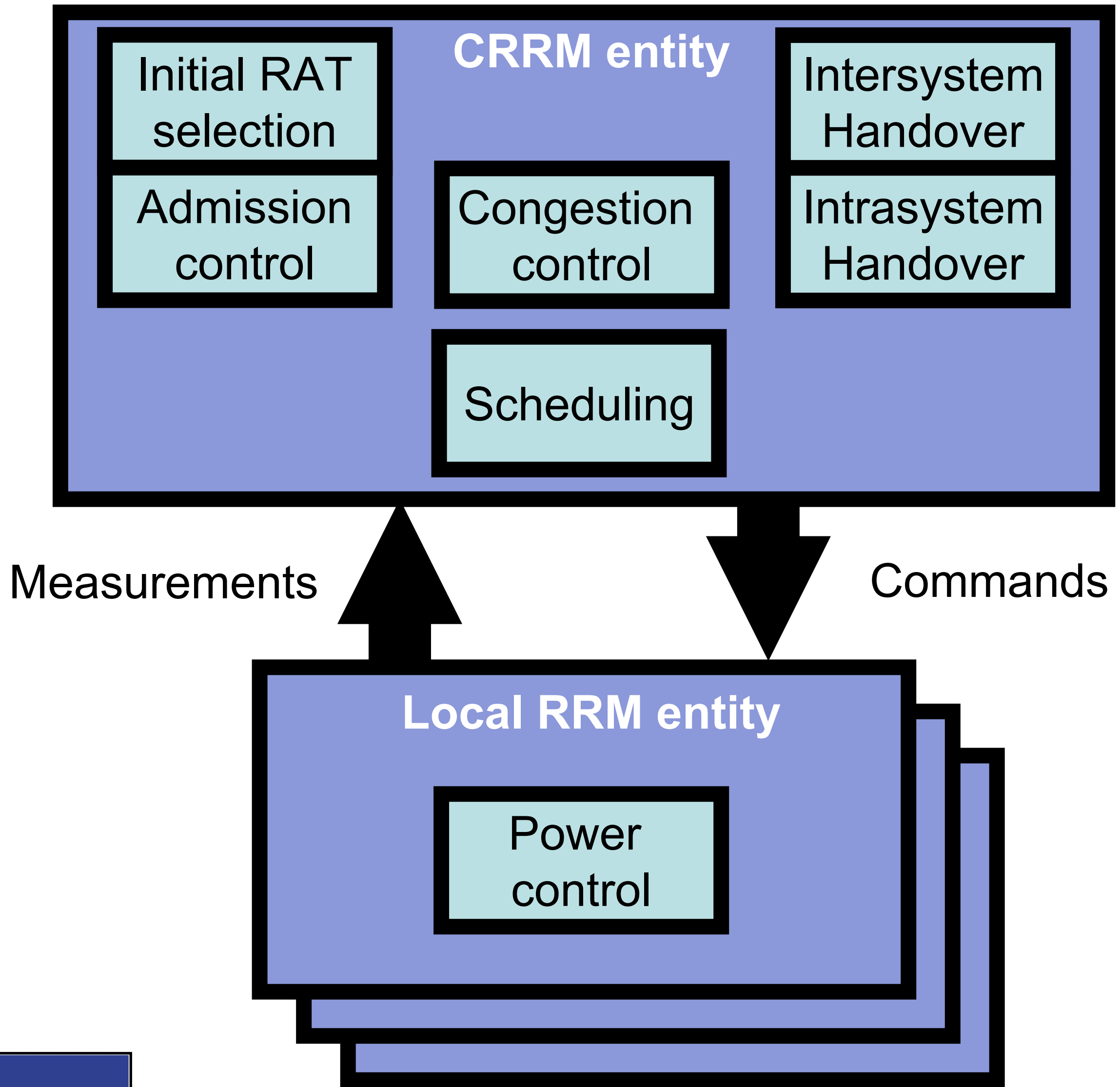


See publications of the working group of Jordi Pérez Romero (UPC)

Medium Scale Integration Level



High Scale Integration Level



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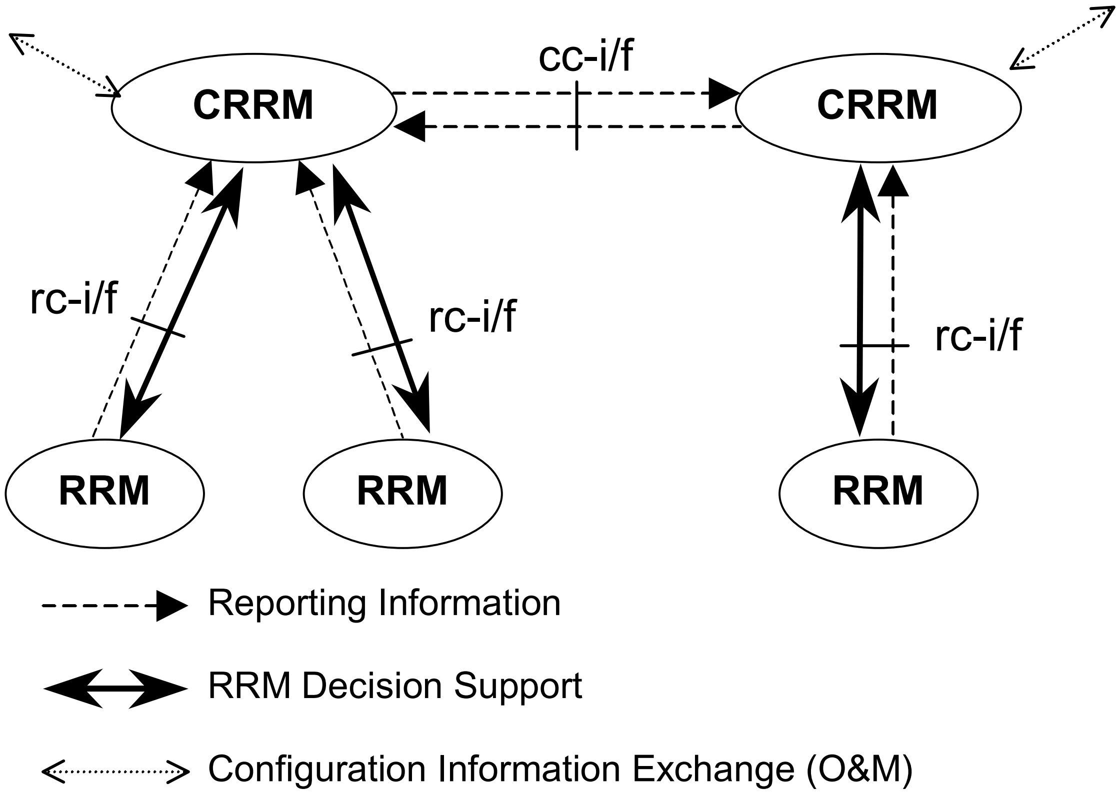
CRRM Functional Model

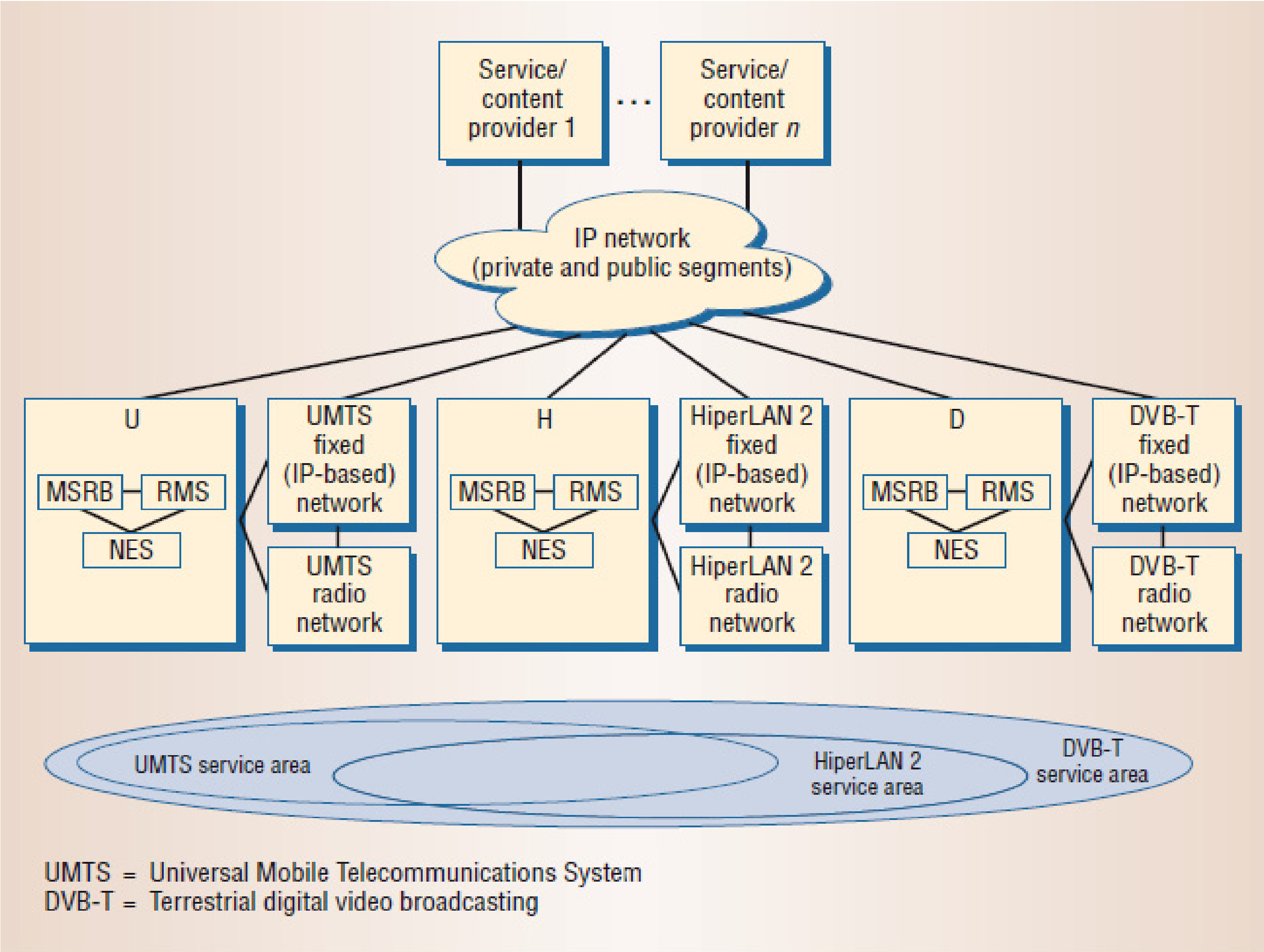
- 3GPP: TR 25.891 ; TR 25.881 ; TR 22.934



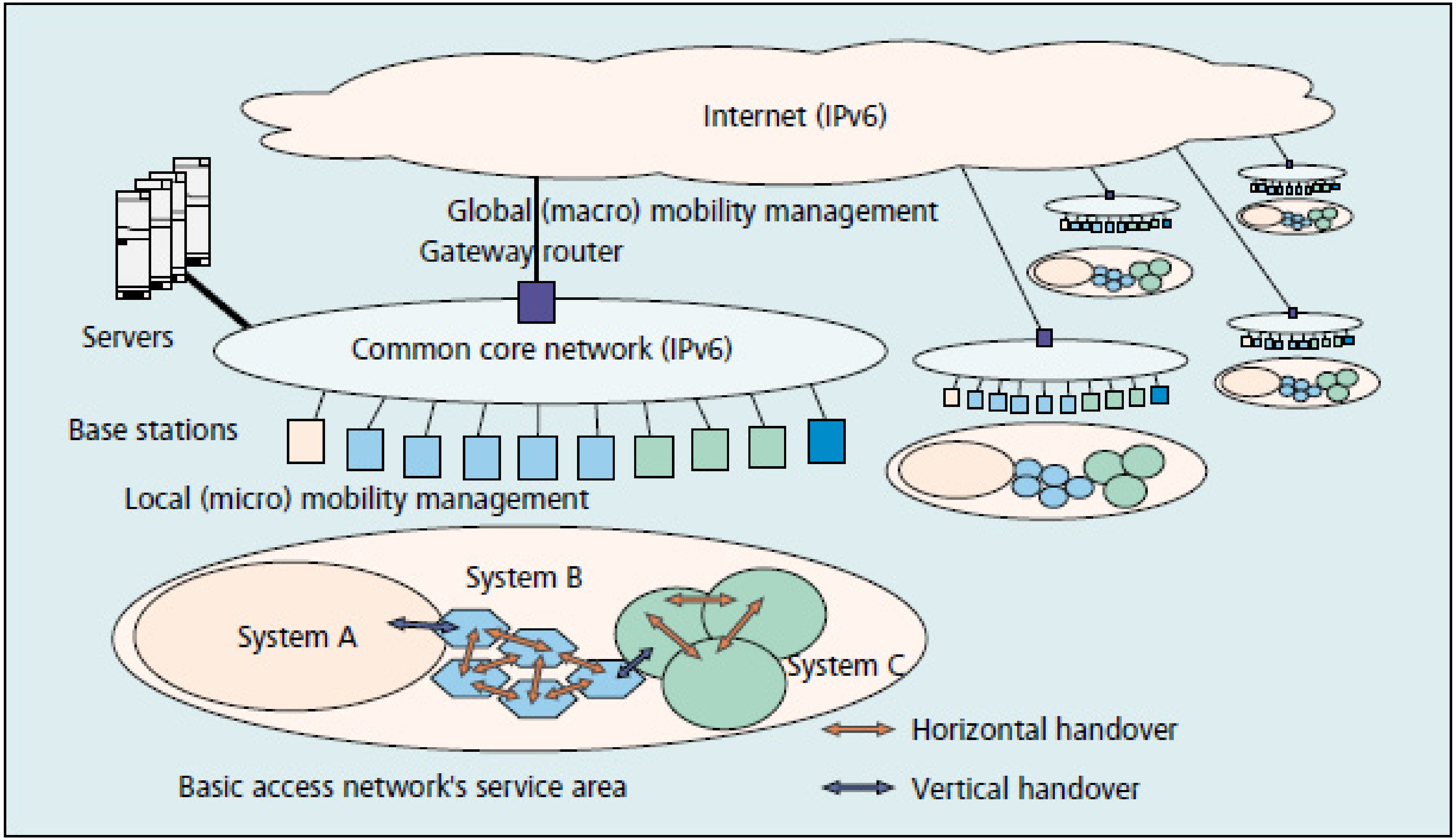
Example Architectures

- A wide variety of architecture examples can be found in literature.
- Just two examples…
  - SNRM: Evaluate decisions before execution
  - MIRAI: Basic access network
- Advantages? Disadvantages?

Service and Network Resource Management (SNRM)



MIRAI Architecture for heterogeneous Networks



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Algorithms Overview

- **Based on multiobjective optimization**
- **Optimal vs. Suboptimal**
- **Predictive vs. Non-predictive**
- Influencing factors
  - Network load
    - Resource utilization
  - Service costs (revenue)
    - Service class (gold, best effort)
  - QoS (blocking, dropping, data rate, delay)
    - user satisfaction
  - Path loss (coverage)
  - Speed
  - Security
  - Energy consumption

CRRM Algorithm Flavors (1)

Mathematical optimization

- Linear programming
  - Set of cost functions
- Integer programming
  - Knapsack problem formulation
- Dynamic programming
  - Solve subproblems

Mathematical optimization: Example: Multiple Knapsack problem formulation (1)

- **M** = available cells; **N** = active sessions; $i \in M, j \in N$
- **c** = cell capacity; **x** = session
- **p** = profit/costs; **w** = resource consumption

- **Restrictions:**
  - Each session is unique: $\sum_{i=1}^{m} x_{ij} \leq 1$
  - Session is indivisible: $x_{ij} = \{0,1\}$

- **Task:**
  - Find a session distribution: $\sum_{j=1}^{n} w_j x_{ij} \leq c_i$
  - Which maximizes profit:
  - Which minimizes costs: $\sum_{i=1}^{m} \sum_{j=1}^{n} p_j x_{ij}$

Mathematical optimization: From MKP to Generalized Assignment Problem (GAP) (2)

- Problems in defining the profit
  - Fixed profit is comparable to prioritization
  - Dynamic profit (e.g. QoS level) depends on connection

$$\sum_{i=1}^{m}\sum_{j=1}^{n} p_j x_{ij} \quad \longrightarrow \quad \sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij} x_{ij}$$

- Problems in finding an optimal distribution of sessions:
  - assignment restrictions / capacity regions
  - varying resource consumption

$$\sum_{j=1}^{n} w_j x_{ij} \le c_i \quad \longrightarrow \quad \sum_{j=1}^{n} w_{ij} x_{ij} \le c_{ij}$$

- **Exact solution is NP-complete -> Approximations**
  - **For MKP a PTAS exist but GAP is assumed to be APX-hard**

Mathematical optimization: Example: Multiple Knapsack problem formulation (3)

Cell capacity definition

- Fixed: maximum throughput; maximum power
- Dynamic: Current throughput in relation to current overall resource consumption
  - Reflects current interference situation

Costs/ Profit/ Weight definition

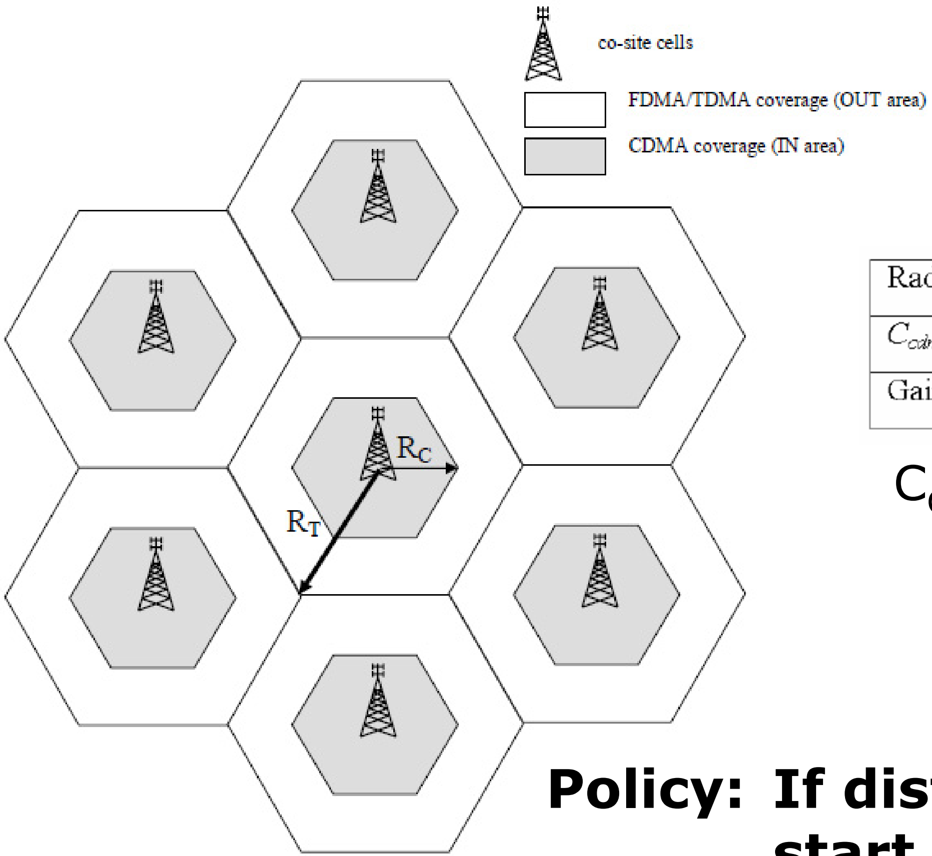
- Very simple weight: data rate of session
- More suitable weights/costs per bandwidth unit (e.g. based on power or time slot consumption)
  - Can be estimated individually (speed, position…)
  - Problems with nonlinearities (e.g. WCDMA)
  - More information has to be transferred
- Profit as a function of user satisfaction…

CRRM Algorithm Flavors (2)

- **Policy based**
- Thresholds or linear programming lead to decisions
- Based on
  - User satisfaction
  - Cell load
  - Path loss
  - Speed
  - General cost functions

Policy based:
Example: Path Loss

- Decision for intersystem handover is based on distance of UE to base station



R_C

Radius in m	1000	900	800	700	600	500
C_{cdma}	30	38	45	55	69	91
Gain (%)	0	27	18	22	25	31

C_{CDMA}: Number of supported voice channels in CDMA cell

Policy: If distance of UE is higher than R_C start intersystem handover to TDMA

CRRM Algorithm Flavors (3)

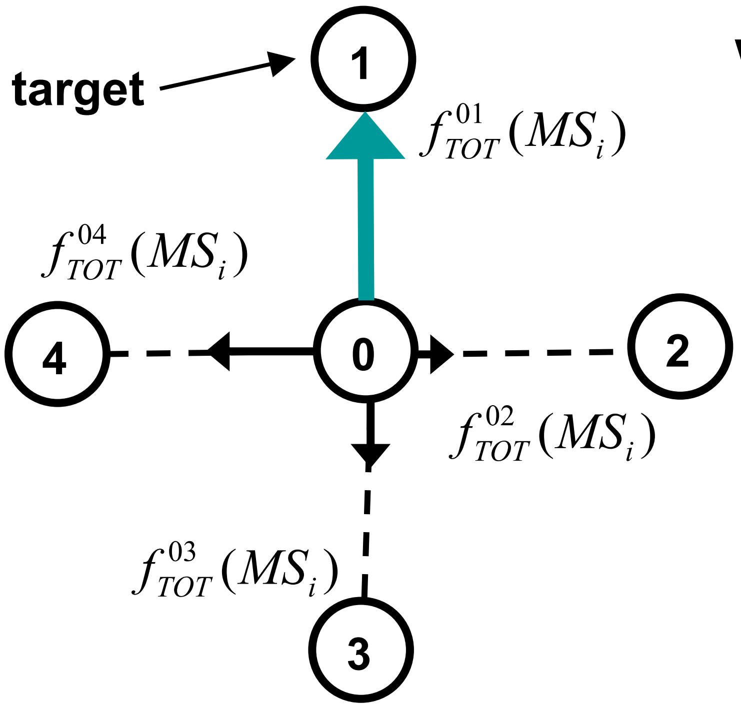
- **Physic / Nature analogy models**
- Force based
  - Attracting/repelling forces
    - cost functions for service sessions based on target cells
- Ecology based
  - Lotka-Volterra competition equations
    - Species compete for resources (growth rate)
    - Species (service), population (traffic), resource (user with coverage), carrying capacity (max. traffic volume of cell), birth (service session starts), death (service session ends)
- Genetic / evolutionary algorithms
  - inheritance, mutation, selection, recombination
    - Incremental approximate solution
    - Problem formulation based on Knapsack (connection, RAS, resource consumption) or set of cost functions

Physic / Nature analogy based: Example: Forces

- The choice of the appropriate target cell is based on superposition of different forces to target cell k

$$f_{TOT}^{j->k}(UE_i) = c_L f_L^{j->k}(UE_i) + c_{QoS} f_{QoS}^{j->k}(UE_i) - c_{CC} f_{CC}^{j->k}(UE_i) - c_M f_M^{j->k}(UE_i)$$

weights **extenuating forces**



- f_L : load in target cell
- f_{QoS} : differences in QoS
- f_{CC} : handover costs
- f_M : time since previous performed intersystem handover

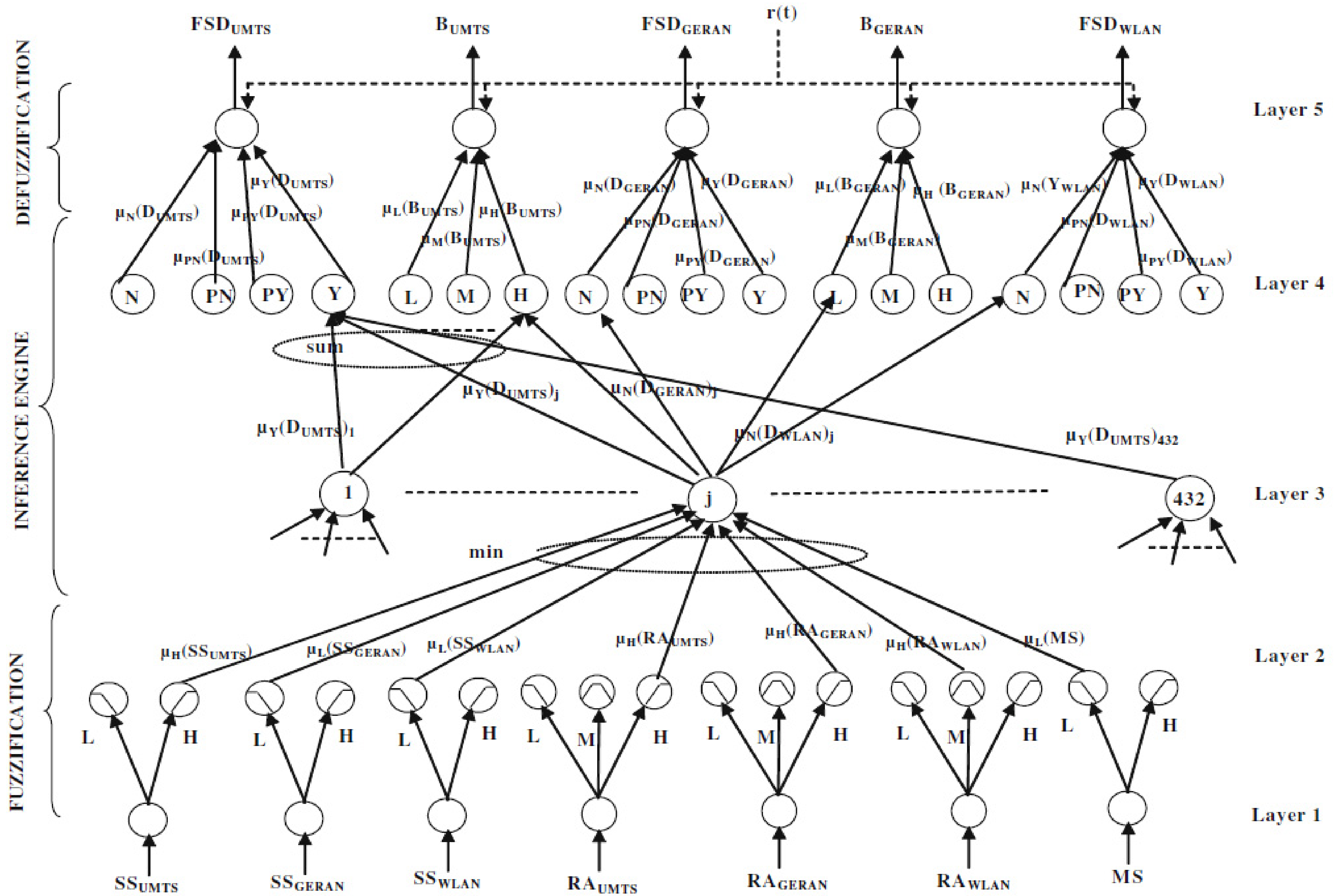
CRRM Algorithm Flavors (4)

- **Game Theory**
- Cooperative
  - Players choose the strategies based on consensus and external rules
    - Find coalition
    - Best payment/revenue
    - Networks form coalitions to handle resource request
- Noncooperative
  - Players make decisions independently
    - Find equilibrium
    - Best strategy
    - Networks admit connections to maximize own revenue
    - Intersystem handover handled via bargaining games

CRRM Algorithm Flavors (5)

- **"Artificial Intelligence" concepts**
- Fuzzy Logic
  - Reasoning that is approximate rather than precise
    - degree of truth (load level in cell, RAT suitable for service, level of resource consumption…)
- Neural Networks
  - Adaptive system that changes its structure based on external or internal information
    - non-linear statistical data modeling
    - Find pattern and relationships
    - Set of influencing factors (speed, data rate, position,…)
    - Reinforcement learning based on achieved QoS

Artificial Intelligence concepts
Example: Fuzzy-Neural Controller



GIUPPONI, L. ; AGUSTÍ, R. ; PÉREZ-ROMERO, J. ; SALLENT, O.: A framework for JRRM with resource reservation and multiservice provisioning in heterogeneous networks. In: *Mobile Networks and Applications*, Volume 11 (2006), Nr. 6, pp. 825-846

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Summary

- **CRRM Problem:** Find matching for set of UE (service sessions) and set of available RAS
- **Actions:** Handover (intra/intersystem), adapt offered QoS, change RRM-properties
- **Goal:** Always best connected at minimal costs
- **Gains:** Trunking efficiency gain,
  Service assignment gain
- **Solution:** multiobjective optimization problem
- **Many open research problems**

End of Presentation

Thank you very much for your attention!

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