Approaches for Radio Resource Management in Mobile Wireless Networks: Current Status and Future Issues

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Abstract: The rapid growth of wireless mobile community, coupled with their demands for high speed, wide band, multimedia services, stands in clear contrast to the limited radio spectrum allocated in international agreements. So radio resource management (RRM) remains as a key challenge to the efficient engineering of mobile wireless networks. In this report, we present an overview of the current status of RRM polices and outline the key issues in RRM for next generation mobile wireless networks.

Keywords- Wireless networks, cellular mobile, radio resource, channel assignment, handoff, cell hierarchy, QoS, software radio.

1.0. Introduction

In mobile wireless networks, all available radio resources (transmitter powers, channels and base stations) must be used in the most efficient way in order to utilize better the scarce radio spectrum. Efficient use of radio spectrum [1] is very important from a cost-of-service point of view, where the number of base stations (BSs) required to cover a given geographical area is a crucial factor. It directly affects an operator's cost structure, and, for a given service and grade of service, it determines: required amount of spectrum (CapEx), required number of BSs (CapEx, OpEx), required number of sites and associated site maintenance (OpEx), and, ultimately, consumer pricing and affordability. A reduction in the number of BSs, and, hence, in the cost of service, can be achieved by more efficient reuse of the radio spectrum [2]. Hence, an increased spectral efficiency improves operator economics in terms of: reduced equipment CapEx/OpEx per subscriber, reduced numbers of sites in capacity limited areas, and reduced spectrum requirements. It also reduces barriers to new operators and new services as it makes a better use of available spectrum, which is especially important for limited spectrum suitable for mobile applications. It improves end-user affordability, especially for broadband services because the cost of service delivery is directly reflected in service pricing, and the cost of delivering broadband services is higher than cost to deliver voice only. Emerging wireless access systems are however, expected to carry both voice and data as well as a mixture of services with very different and often conflicting service requirements [6]. As we are moving towards the next generation of mobile systems, the need for improving coverage, systems capacity and service quality becomes more and more important. Different service classes have different QoS requirements. Future services will also have widely varying QoS requirements. The network must handle these requirements in order to satisfy end-users without wasting network resources. Moreover, to have any meaning, QoS provisioning must be end-to-end (i.e., right from service to terminal). The radio interface is the scarcest resource in the mobile network and is a rather hostile environment, being error-prone and subject to radio propagation conditions that can vary over time. Consequently, effective QoS management in the radio network layer of the mobile network is a must. RRM will be the major differentiator between the overall QoS provisioning offered by different operators' networks.

1.1 Radio Resource Management (RRM) Problem

Before discussing the management techniques, let us briefly describe the RRM problem as formulated in [2]. Let us assume that M mobile terminals (MTs) are served by B base stations (BSs), numbered from the set *B* = {1,2,3, ..., B}. Let us also assume that there are C orthogonal channel pairs numbered from the set *C* = {1,2,3, ..., C} available for establishing links between BSs and MTs. To establish radio links, the system has to assign to each MT: a) a BS from the set *B*, b) a channel from the set *C*, and c) a transmitter power for the access port and the terminal. This assignment is performed according to some *resource allocation algorithm* (RAA) built in the system. The assignment is restricted by the interference caused by the BSs and MTs as soon as they are assigned a "channel" and when they start using it. Another common restriction is that BSs are, in many cases, use only a subset of the available channels. Good allocation schemes will aim at assigning links with adequate signal-to-interference ratio (SIR) to as many (possibly all) MTs as possible. Note that the RAA may well (should) opt for not assigning a channel to an active MT, if this assignment would cause excessive interference to other MTs. Spectral Efficiency is defined as a measure of the amount of information – billable services – that is carried by a wireless system per unit of spectrum. It is measured in bits/second/Hertz/cell, and includes effects of multiple access method, modulation methods, channel organization, resource reuse (code, timeslot, carrier, …). RRM views handoff and other resource management tasks that include admission control, channel assignment and power control, used to improve system performance. A major challenge in the wireless networks is to guarantee quality of service (QoS) requirements, while taking into account the radio frequency spectrum limitations and radio propagation impairments. As the demand for wireless service increases, managing radio resource becomes more complicated. Figure 1 depicts the generic functional blocks used for RRM in a typical cellular system. This shows that CA strategy has to be supported by handoff strategy, power control and call admission control (CAC) in order to entail a balanced RRM.

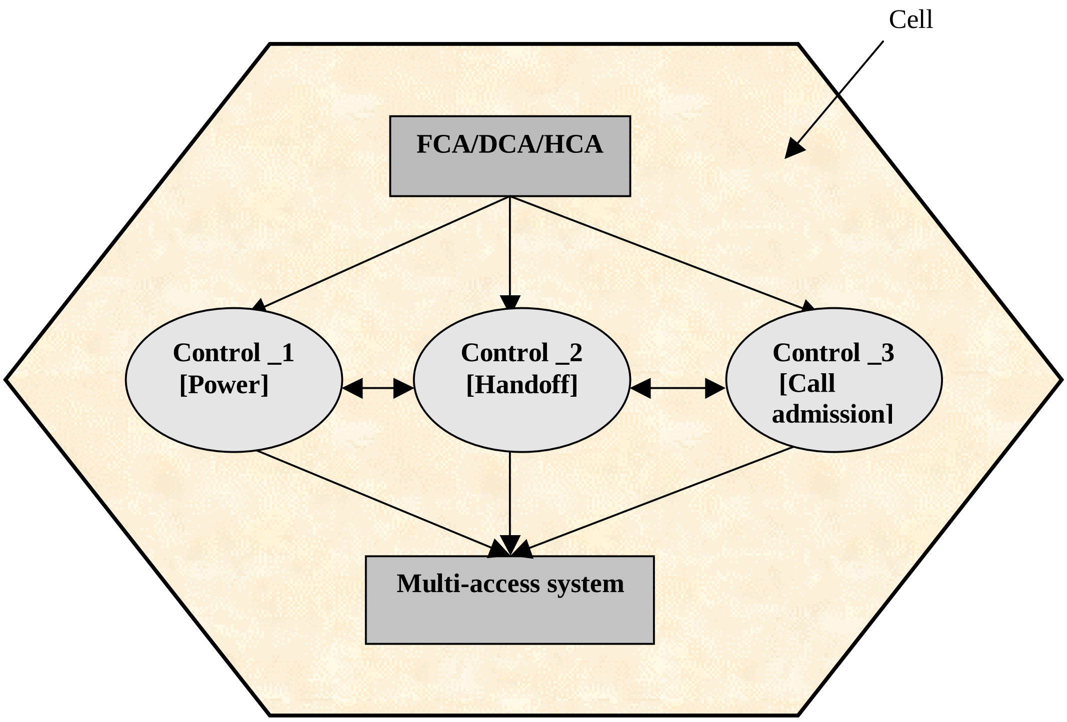

Figure 1: Generic Function Blocks of an RRM System

2.0 RRM Schemes

Tools used to designing for spectral efficiency are of two types: Spectral/Temporal, and Spatial. Spectral/Temporal tools include multiple access methods, data compression (or source coding techniques), modulation, channel coding, and equalization. Spatial tools (to minimize interference) include cellularization, sectorization, and power control. Temporal/Spectral aspects are mature, well-understood, well exploited; no significant future improvements are probable here. Least spectrally efficient aspect of most systems is sectorized distribution and collection of radio energy, where most of the energy is wasted; worse, it creates interference in the system and limits reuse.

2.1Channel Allocations

An interesting subproblem of the general RRM problem that has attracted much attention in the literature is the choice and allocation of channels. Dividing the spectrum into a set of channels (i.e., identifying C) is the first step in RRM. A given radio spectrum (or bandwidth) can be divided into a set of disjoint or non-interfering radio channels. All such channels can be used to maintain an acceptable received radio signal. Many techniques, such as frequency division (FD), time division (TD), or code division (CD), can be used in order to divide a given radio spectrum into channels (i.e., “channelization” of the spectrum). In FD, the spectrum is divided into disjoint frequency bands, while in TD the channel separation is achieved by dividing the usage of the channel into disjoint time periods called time slots. In CD, the channel separation is achieved by using different modulation codes. Also, dividing each frequency band of an FD scheme into time slots can use a combination of TD and FD. The major driving factor in determining the number of channels (with certain quality) that can be used for a given wireless spectrum is the level of received signal quality that can be achieved in each channel. Classical orthogonalization techniques, such as FD multiple access (FDMA) and TD multiple access (TDMA) are very common and used extensively in various systems. However, they are now being challenged by non-orthogonal waveform systems of CD multiple access (CDMA) [3], [4].

2.2. Channel Assignment

Channel Assignment (CA) is the next point of debate in RRM. It has been conventionally solved in three ways, namely fixed (F), dynamic (D) and hybrid (H). We discuss them briefly.

2.2.1 Fixed Channel Assignment (FCA)

Many of today's communication systems use FCA, and it mostly operates on a long-term basis. Based on an average statistical information regarding link (power) gain (i.e., large scale propagation predictions), frequencies are assigned to different BSs on a permanent basis. Such a cell plan provides a sufficient reuse distance between BSs, providing a reasonably low probability of outage to low SIR [1]. To minimize the planning effort, adaptive cell planning strategies (e.g., “channel segregation” [2]) have been devised using long-term average measurements of the interference and traffic to automatically allocate channels to the BS.

FCA works quite well, when employed in macrocellular systems with high traffic loads. In short range (microcellular) systems and in multimedia traffic scenarios, "static" channel allocation schemes require considerable design margins to cope with the large variations in propagation conditions and traffic load. Large path loss variations are countered with large reuse distances, unfortunately at a substantial capacity penalty. In the same way, microcellular traffic variations are handled by assigning excess capacity to handle traffic peaks.

2.2.2. Dynamic Channel Assignment (DCA)

In recent years, to improve the trunking efficiency, resources are shared more efficiently between the cells in a dynamic way (DCA). In DCA, all channels are placed in a pool and are assigned to new calls as needed such that the threshold criterion of CIR (called CIR_{min}) is satisfied. At the cost of higher complexity, DCA schemes provide flexibility and traffic adaptability. A number of dynamic channel selection strategies based on interference has been shown to outperform FCA [4].

2.2.3 Hybrid Channel Assignment (HCA)

DCA strategies are less efficient under high load conditions. To overcome this drawback, HCA techniques were designed by combining FCA and DCA schemes [1]. In HCA, the total number of channels available for service is divided into fixed and dynamic sets. The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes, and, in all cases, are to be preferred for use in their respective cells. On the other hand, all users share the dynamic set of channels in the system to increase flexibility. When a call requires service from a cell and all of its nominal channels are busy, a channel from the dynamic set (if available) is assigned to the call.

2.3. Handoff Process

An issue, closely related to CA, is handoff, which is usually associated with the movement of MTs. Handoff is a process of transferring an MT from one BS (or channel) to another. For this, the channel change might be through a time slot, frequency band, codeword or combination of these for TDMA, FDMA, CDMA or a hybrid scheme, respectively [9]. Handoff algorithms with a specific set of parameters cannot perform uniformly in different wireless architectures because they are characterized by specific environment parameters. Handoff can be broadly classified into network-controlled (or hard) handoff, and mobile-controlled (or soft) handoff [3], [7].

Prioritizing handoff is one way to achieve significant reduction in handoff blocking rates, while only incurring a remarkably small increase in the new call blocking rates. Several handoff prioritization schemes, such as guard channel and queuing, are used in modern systems [8]. A scheme, called predictive channel reservation [9], works by sending reservation requests to neighboring cells by extrapolating the motion of MTs. A number of design enhancements are incorporated in this scheme, to minimize the effect of false reservations and to improve the throughput of the cellular system.

2.4. Quality of Service (QoS)

Optimal usage of the soft capacity to provide, maintains, and guarantee QoS for different service classes is now becoming a very important issue. A few numbers of RRA schemes, primarily for CDMA-based systems, have been proposed in [5] that are flexible, support traffic services with various QoS requirements, minimize call/session blocking and dropping probabilities, and have acceptable radio resource utilization. Jointly considering the physical, link, and network layer characteristics a RRM scheme is proposed [10] for the support of QoS in cellular CDMA systems. At the link layer, a packet-scheduling scheme is developed, based on information derived from power distribution and rate allocation, to achieve QoS guarantee. Packet scheduling efficiently utilizes the system resources in every time slot and improves the packet throughput for non-real-time traffic.

Currently, multimedia traffic is used frequently in wireless networks. To provide Qos guarantees for this traffic, a probabilistic resource estimation and semi-reservation scheme [5] is used to improve the connection blocking probability, connection dropping probability, and bandwidth utilization.

3. Call Admission Control (CAC)

CAC denotes the process of making a decision for every new call admission according to the amount of available resource versus users' QoS requirements, and the effect upon the QoS of the existing calls imposed by each new call. Whenever a new MT (either a new request or an intercell handoff) arrives in a BS, the RRM system has to decide if this particular MT may be allowed into the system. An algorithm making these decisions is called a *CAC algorithm* [1]. CAC can be divided into two groups: *interference-based* and *user-based*. In interference-based algorithm, admission control is based on the CIR parameter, while user-based algorithms are dependent on the number of channels available.

Traditional approaches involving FCA normally use simple thresholding strategies on the available channels in each cell. This traditional CAC algorithm is known as the *guard channel algorithm*. There are also some non-traditional methods proposed recently [8]. They are based on adaptive techniques, where channels are allocated and reserved in a dynamic way using teletraffic analysis, prediction of injected traffic and prediction of MT movement. In some prediction schemes, it is sufficient to reserve the radio resource that the MT will need in the predicted location. In general, the resource reservation mechanism consists of two parts; i) some of the bandwidth reserved in the next cell the MT is likely to visit, and ii) a common pool of dynamically adjusted bandwidth used to accommodate other unpredicted flows. The next cell is predicted based on the mobility pattern observed in various cells. Other similar approaches include schemes, which rely on the extended location information (from adjacent cells) to make the CAC decision. The bandwidth reservation could be estimated based upon the history of the nominal cell and neighbouring cells. Queuing of a handoff request is more sensitive to delay in service than queuing of a new call, leading to queuing of new calls rather than handoff calls. One of the key point of using queuing in CAC is that service differentiation can be managed with queuing discipline. Instead of FIFO queuing strategy, other prioritized queuing discipline can be used to maintain priority level in each service class.

4. RRM Related Techniques

Cellular systems with requirements for higher spectral efficiency need to improve system capacity using efficient RRM techniques. Techniques, such as hierarchical structure cell splitting, sectoring, adaptive antenna and software radio that could be used to expand the system capacity, are discussed in this section.

4.1 Hierarchical Architecture

Underlay/overlay (or, overlay/underlay) architecture can be used to increase system capacity, performance and coverage. Conventional cellular systems follow overlay/underlay structure, where clusters of cells are usually grouped into a location area. Underlay/overlay differs from overlay/underlay in that a tighter reuse factor is used within the former. Figure 2 illustrate the hierarchical architecture of underlay and overlay systems. For example, a single overlay macrocell can be divided into two underlay clusters of microcells in an underlay/overlay system, hence increasing the number of channels in the whole system.

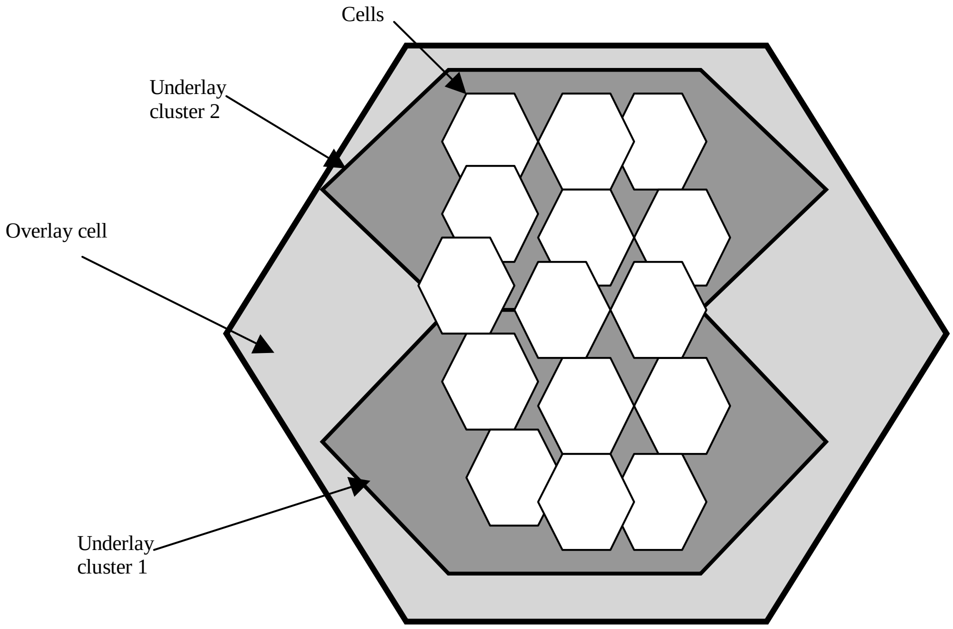

Figure 2: Hierarchical Architecture

4.2 Reuse Partitioning

A common method to increase the spectral efficiency in cellular systems is reuse partitioning (RUP). In RUP, each cell in the system is divided into two or more concentric subcells or zones as shown in Figure 3. The inner zone (closest to the base station) requires lower power levels to achieve the desired CIR than the outer zone. Therefore the minimum reuse distance for the inner zone becomes smaller than that for the outer zone, which leads to a higher spectrum efficiency. RUP can be divided into fixed and adaptive techniques. Another variant of partitioning, called multiple channel bandwidth system (MCSB), can be utilized to increase the spectral efficiency. In MCSB, a cell is also divided in two or more concentric subcells. To achieve the desired CIR, the inner zone requires less bandwidth per user than that required by the outer zone, thereby making more channels available in the inner zone. Thus, instead of utilizing the same amount of bandwidth per user throughout the whole cell, the MCBS can be used to increase the number of channels in a cell.

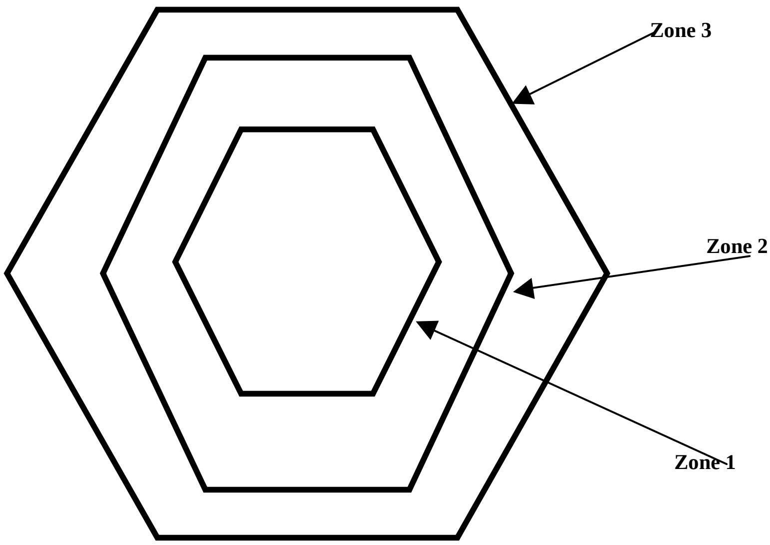

Figure 3:Concentric Subcells

4.3 Adaptive Antenna

Adaptive antennas are spatial processing systems consisting of a combination of antenna arrays and sophisticated signal processing techniques. They can adapt the effective pattern to the radio environment, depending upon the position of MTs by providing spatially selective transmit and receive patterns. Instead of wastefully broadcasting personal communications, such as cell-phone calls, in all directions, these innovative antennas track the positions of MTs and deliver radio signals directly to them. This results in an improved gain and interference mitigation, leading to an improved signal quality and spectral efficiency. These antenna systems also maximize the reception of an individual MT's signal, while minimizing the interference from other MTs. In effect, the antennas can vastly improve wireless communications by creating a virtual wire extending to each MT.

4.4 Cell Sectoring

Cell sectorization [8] improves the capacity in CDMA systems. The use of adaptive antenna arrays with dynamic cell sectoring is particularly suitable for non-uniformly distributed users. Traditional sectoring divides the cell into equal width sectors that are suitable for uniform traffic load. However, for non-uniformly distributed call traffic, such fixed sectoring approach might fail to bring much capacity improvement, and the sectors with high-density traffic may suffer high outage probability. This deficiency can be eliminated by the use of adaptive cell sectorization, i.e., the cell widths are adaptively adjusted according to call traffic distributed over service areas. This is particularly well justified for the recent developments on fixed wireless systems, in which users' locations (and thus their uplink gains to the based station) do not change much with time, and such information can be obtained at the base station without much effort. In the adaptive cell sectorization, the key problem is to determine the direction and width of each sector to minimize the total transmission power and, at the same time, maintaining each user's QoS requirements, specifically, the SIR experienced by the users in CDMA systems.

4.5 Software Radio [7]

A software defined radio (SDR) is a radio whose channel modulation waveforms are defined in software, i.e., waveforms are generated as sampled digital signals, converted from digital to analog and then possibly up-converted from IF to RF. The receiver, similarly, employs a wideband converter that captures all of the channels of the software radio node. The receiver then extracts, down converts and demodulates the channel waveform using software on a general-purpose processor. SDR extends the evolution of programmable hardware, increasing flexibility via increased programmability. The use of a SDR that can program a specific waveform for use in different wireless settings will make it possible to adapt the link to changing conditions. Such an approach is also expected to facilitate the management of QoS. The terminal re-configurability provided by SDR technology introduces flexibility in spectrum management when different heterogeneous radio systems exist in the same geographical area. Development of such a software radio would help develop commercial products that can handle several services (e.g., AMPS, DAMPS, GSM, PCS, CDMA) in a single region. Recently, SDR is being enhanced to produce Cognitive Radio, an emerging topic within software radio. It refers to that class of software radio, which employs model-based reasoning, and at least a chess-program level of sophistication in using, planning, and creating radio etiquettes. It represents an ideal situation that may never be fully implemented; but that nevertheless simplifies and illuminates tradeoffs in radio architectures that seek to balance standards compatibility, technology insertion and the compelling economics of today's highly competitive marketplaces.

5. Ubiquitous RRM Techniques

The emergence of a variety of mobile data services with variable coverage, bandwidth, and handoff strategies has attracted tremendous attention to the need for roaming among different radio access networks in a hybrid network architecture. The capabilities of network operators' current infrastructure and form part of this multi-radio hybrid network, maximizing the usage of existing network investments. For this vision to work, different technologies must be seamlessly integrated to form a single access network so that the end user will be unaware of the access technology being used. Similarly, from the operation and management point of view, these different technologies must be fully integrated to form a single network. Managing these technologies separately will be expensive, resulting in low resource usage and poor network quality. Moreover, hybrid networks will take advantage of the properties in the existing networks to provide a wider coverage and to serve all types of service classes. However, in a network with a mixture of resources (different systems and different layers) and offering a mixture of different services, it is vital to provide the optimum radio bearer for each service, based on the QoS requirements of the service. Over provisioning QoS to those services or users (that do not require it) will waste network resources and should be avoided.

One solution to exploit hybrid networks is to provide a single integrated handoff and CAC strategy. For example, Figure 4 depicts the model of an integrated access system with a virtual RRM access node. This virtual node acts like a control plane in a centralized system. It can provide extra capacity to the network, resulting in higher end-user average bit rates and lower blocking. In particular, it can provide: a) load sharing, congestion control and interference distribution, b) simplified interworking in a multi-vendor/multi-system environment, c) unified radio bearer QoS management, and d) easier operability. However, the challenge lies in the design of an efficient virtual node considering various factors, such as the traffic generated in the system, the cell crossing rate (mobility analysis) and traffic overflowing amongst different radio access networks.

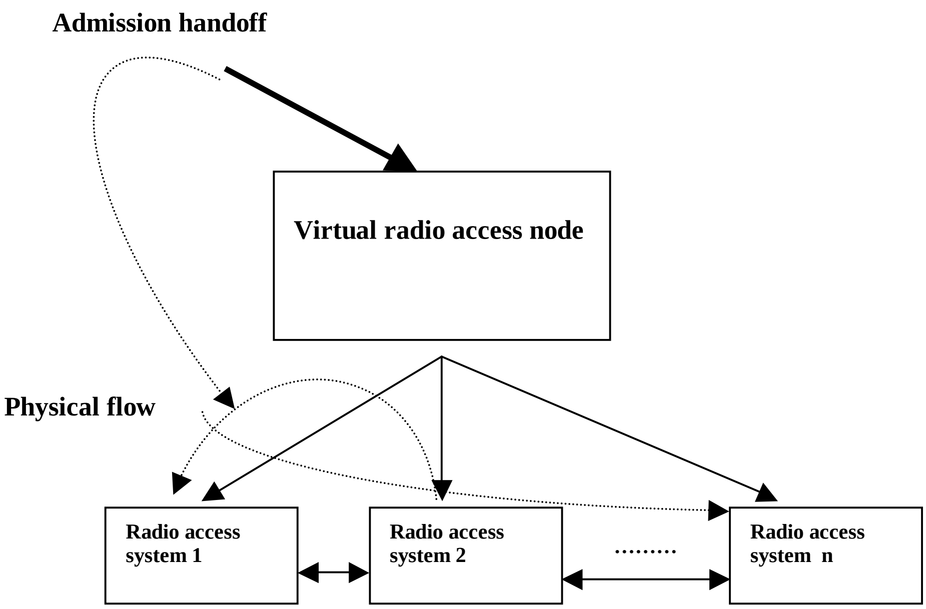

Figure 4: Model of a virtual access node

Another important issue is to ensure that the terminal is directed to the optimum bearer, ensuring both that network resources are efficiently used and that the end user receives the required QoS. This will lead to higher user bit rate and lower blocking. Such a scheme can reduce unnecessary air interface signaling, core network signaling and intersystem measurements too.

Discussion and Conclusion

The rapid growth in demand for mobile communication has led to intense research and development efforts towards a new generation of cellular systems. Examples of different system architectures include macrocells, microcells, picocells, overlays, integrated cellular systems, and satellite systems. In future, these systems will co-exist in mobile wireless communication systems and the new system must be able to provide QoS, support a wide range of services while improving the system capacity. Traditionally, since we consider frequency spectrum to be the resource to be shared, it is important that we widen the resource management perspective. The design and performance of RRM algorithms is not affected much by the increase in bandwidth *per se*. In fact, much of the on-air signaling required by many of the adaptive schemes will, relatively speaking, occupy a smaller fraction of the available bandwidth. The key question here is: whether it will be thin client i.e., cell infrastructure be very dense and costly allowing for cheap, low power terminals, or it will be thick client i.e., terminals be more complex allowing for the rapid deployment of a cheap infrastructure at the expense of battery life and terminal cost? The current trend is biased towards the former.

Increasing the infrastructure density with more BSs will clearly cause an increase in complexity in the RRM algorithms. Future systems are expected to require much higher data rates than current systems. So, either the investment will have to be heavily in a dense ubiquitous infrastructure, or be limited to covering only certain areas where users will require extensive bandwidth requirements.

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