April 2012 IJMIE Volume 2, Issue 4 ISSN: 2249-0558

CHALLENGES IN ALLOCATION OF RESOURCES IN FUTURE CELLULAR MOBILE NETWORKS

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Abstract:

Efficient resource sharing is very important in mobile networks to provide satisfactory service to customers. The resource demand is increasing due to increasing number of user population and high bandwidth demanding multimedia applications. The mobility of users and multimedia applications are changing the dynamics of traffic. This paper discusses framework of problem for radio resource allocation and management considering key resources. This paper also discuses current approaches in radio resource allocation and looks into radio resource management problem formulation and challenges in future cellular mobile networks.

Keywords- Resource allocation, blocking probability, dropping probability, multimedia traffic, traffic Intensity.

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1 Introduction:

There is rapid increase in the size of wireless mobile user community during last decade. The demands for high speed, multimedia communications for voice and data, is also growing day by day. This is in clear contrast to the rather limited spectrum resource that has been allocated in international agreements. The key challenge in a multi-service system is that the radio resources should be properly allocated among multiple traffic classes so that QoS needs of each traffic class can be satisfied while utilizing the resources efficiently and effectively to the extent possible. In cellular systems, handoff calls resulting from user mobility make resource sharing even more difficult.

Fig 1 illustrates the general architecture of a cellular mobile network [1]. The network consists of a fixed network part and a wireless access system. The fixed network provides connections between base stations, which in turn provide the wireless "connections" to the mobiles. The BSs are distributed over the geographical area where we wish to provide the mobile users with communication services.

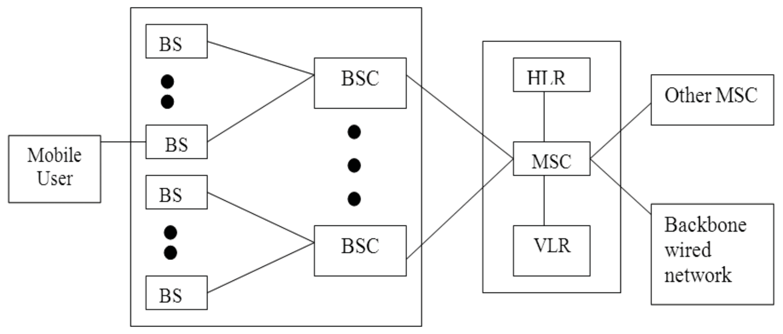

Figure 1 General Architecture of the Cellular Network Systems

For obvious economical reasons, we would like our wireless network to provide ample coverage with

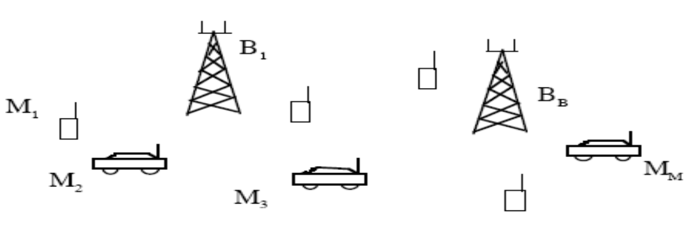

Fig 2 Resource management problem formulation as few base stations as possible.

In the remainder of the chapter we will now present a more rigorous formulation of the radio resource allocation and review some of the ideas and results from the literature.

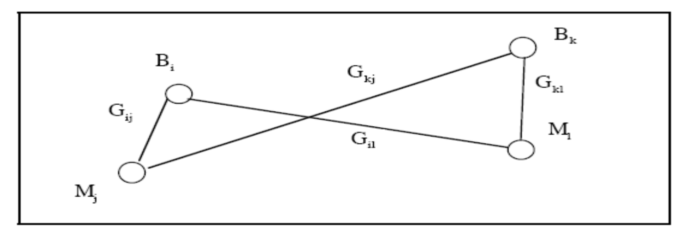

Fig 3 Link Gains

Finally we give an outlook on how these results can be applied to future wideband systems and which are the key problems that should be addressed in further studies.

2. Radio resource allocation - a general problem formulation:

We assume that there are M mobiles (*1, 2, 3.... M*) to be served by base stations, numbered from the set = {*1,2,3,...B*}. Now, let us assume that there are *C* orthogonal channels (channel pairs)) numbered from the set= {*1,2,3,...C*} available for setup links between access ports and mobile terminals. Disjoint set of these C channels are distributed in each of the cells in a cluster. This frequency distribution is reused in the neighboring clusters. To establish radio links, to each mobile the system has to assign

a) A base station from the set,

b) A channel from the set,

c) A transmitter power for the base station and the terminal.

In this paper, we propose a call level optimum resource allocation scheme and adaptive call admission control (CAC) policies for packet-switched voice/data integrated cellular networks, which can maximize resource utilization under QoS constraints of new call blocking probability (NBP) and handoff call dropping probability HDP). Using the effective bandwidth technique [2], [3], the resources required for a packet switched network to service each call with a physical layer and link layer QoS guarantee can be determined. The assignment is restricted by the co-channel interference caused by the ongoing calls as soon as they are assigned a "channel" and when they start using it. Another common limiting factor is use of only a certain set of channels by base stations to prioritize handoff calls over new calls as for a subscriber dropping of an ongoing call is always more annoying than blocking a new call. Good allocation schemes will aim for higher throughput by assigning links with adequate SIR to as many (possibly all) mobiles as possible while ensuring QoS. The assignment of a channel to an originating call is not recommended if this assignment causes excessive interference to other mobiles and degrades the QoS.

The interference is the main bottleneck on resource allocations. Hence we need to ascertain signal and interference power levels in all base stations and mobiles, given the *link (power) gains*, *Gij*, between base stations *i* and mobile terminal *j*. In order to simplify the calculations, we will here consider only rather wideband modulation schemes which will make the link gains virtually independent of the frequency. We collect all link gains in matrix form, and get a *BxM* rectangular matrix the *link gain matrix G*. The propagation conditions in the system are described in link gain matrix. Note that in a mobile system, both the individual elements of the matrix (due to mobile motion) and the dimension of the matrix (due to the traffic pattern) may vary over time.

The main focus of the Resource allocation scheme is to make assignments or allocations in such a way that provides required Quality-of-Service in as many links as possible (preferably all). This measure is strongly connected with performance measures as the bit or message error probability in the communication link. We require the SIR to exceed a given threshold γ_o which is determined by the modulation and coding formats of the system. This means that the following inequality must hold for both the up (mobile-to-access port) and down (access port-to-mobile) link of the connection:

$$\Gamma_i = \frac{P_j G_{ij}}{\sum_m P_m G_{im} \theta_{jm} + N} \geq \gamma_o \qquad (1)$$

Where τ_j denotes the SIR at the receiver and N denotes the receiver (thermal) noise power at the access port. P_j denotes the transmitter power used by terminal j. The quantity Θ_{jm} is the normalized cross correlation between the signals from mobiles j and m at the access port receiver, i.e. the effective fraction of the received signal power from transmitter m contributes to the interference when receiving the signal from access port j. If the waveforms are chosen to be orthogonal (as in FDMA and TDMA) these correlations are either zero or one depending on if the station has been assigned the same frequency (time slot) or not. In non-orthogonal access schemes (e.g. DS-CDMA) the Θ_{jm} take real values between zero and one.

It may not be possible to comply with all the constraints (2) for all the *M* mobiles, in particular if *M* happens to be a large number. As system designer we need to make consistent efforts to find resource allocation schemes that assign channels to as many mobiles as possible, while keeping new call blocking and handoff call dropping probability minimum. The largest number of users that may be handled by the systems is a measure of the *system capacity*. Since the number of mobiles is random quantity and the constraints (2) depend on the link matrix, i.e. on the relative position of the mobiles, such a capacity measure is not a well defined quantity.

The traditional approach for telephone type of traffic is to use as capacity measure the average relative arrival rate of calls ρ for which the new call *blocking probability and handoff call dropping probability* can be kept below some predetermined level. Because of the mobility of sender and receiver, this is not an entirely satisfying measure. In wireless networks quality a link is time variant. An ongoing call or session may be lost due to adverse poor quality of link or due to speed of sender and/or receiver. To include such phenomena in to our capacity would require detailed specification of call handling procedures (e.g. handling of new vs. old calls, hand-off procedures as mobile moves from one access port to another etc.). It may therefore be practical to choose a simpler and more fundamental capacity measure that will reflect the performance of the resource allocation scheme as such. For this purpose, the *assignment failure probability v* or assignment failure rate [4, 5]) has been proposed. The *instantaneous capacity* $\omega^*(v_o)$ of a wireless system is the maximum allowed traffic load in order to keep the assignment failure rate below some threshold level v_o, i.e..

$$\omega^*(v_o) = \{ \max \omega : v \leq v_o \} \qquad (2)$$

As we have seen above, finding the optimum resource allocation, i.e. for each mobile determining

i) A waveform assignment (determining the Θjm)

ii) An access port assignment (of one or more (!) ports)

iii) A transmitter power assignment

Which maximizes γ for a given link gain matrix, is a complex problem. There is no efficient general algorithm that is capable of doing such an optimal assignment for arbitrary link gain matrices and mobile sets. Instead, partial solution and a number of more less complex heuristic schemes have been proposed (and are used in the wireless systems of today). These schemes are usually characterized by low complexity and by using simple heuristic design rules. The capacity achieved by these schemes is, as expected, often considerably lower that can be expected to be achieved by optimum channel assignment.

3. Current Approaches to resource allocation strategies:

The most of the work done in this area is basically focused is, the selection and allocation of waveforms. The most popular waveforms undoubtedly have been orthogonal waveforms such as frequency division multiplexing (FDMA) and time division (TDMA) that provide a "channelization" of the spectrum, but recently considerable interest has been devoted to non-orthogonal waveforms, e.g. the IS-95 DS-CDMA waveforms [6]. Given the set of signaling waveforms, the next problem is the allocation of waveforms to the different terminal-access port links. This allocation can be done in many ways depending on the amount and quality of the information available regarding the matrix G and the traffic situation (activity of different terminals). The time scale happens to be another important issue on which resource (re-) allocation is feasible.

Channel allocation in early FDMA cellular radio systems operates on a long term basis. Based on average type statistical information regarding G (i.e. large scale propagation predictions), predetermined set of frequencies are permanently basis assigned to different access ports. Such a "cell plan" provides a sufficient reuse distance between base stations providing a reasonably low interference level resulting in reduced call blocking and dropping probabilities. Non-uniform traffic load can also be taken care of by adapting the number of channels in each base station to the expected traffic carried by that access port. In order to minimize the planning effort, adaptive and flexible cell planning strategies (e.g. "channel segregation"[7]) have been devised using long-term average measurements of the interference and traffic to automatically allocate channels to the access port. These types of static channel allocation schemes, work quite well when employed in macro cellular systems with high traffic loads. In short range (microcellular) systems propagation conditions tend to change more abruptly and number of handoff increases considerably due to smaller cells. Since each of the base stations tends to carry less total traffic in small a microcell, the relative traffic variations are also large, particularly due to multimedia traffic scenarios. To employ "static" channel allocation schemes in the situations considerable design margins are required. Large path loss variations are countered with large reuse distances, resulting in substantial capacity penalty. In the same way microcellular traffic variations are handled by assigning excess capacity to handle traffic peaks. In recent years two principally different methods to approach this problem have been devised: *Dynamic* channel allocation (DCA) and *Random* Channel Allocation (RCA) and their numerous combinations together with use of queuing to enhance the efficiency and overall system capacity.

In dynamic (Real-time) channel allocation (DCA), real-time measurements of propagation and/or traffic conditions are used to (re-)allocate spectrum resources. This real time gathering of data is a complex procedure and an extra overhead on the system. Early, graph theoretic schemes, adapted only to traffic variations [8, 9] yielding only moderate capacity gains (<50%) compared to static systems in microcellular environments. Other schemes adapt their channel allocation to the prevailing traffic conditions in the cell. One example of the latter type of schemes is the class of Reuse-partitioning schemes [10, 11]. Here, several overlaid cell plans with different reuse distances are used. Terminals with a high received signal level are tolerant to interference and can be allocated a channel from a dense reuse cell plan whereas the "weaker" terminals get channels with a large reuse distance and lower interference levels. Capacity gains in the order of up to 100% have been reported for these schemes [12]. Also schemes directly estimating the C/I and thereby in a distributed way finding channels with adequate quality have been proposed [7, 13]. Similar gains as in the reuse partitioning schemes are found in the literature. A comprehensive survey of different DCA-schemes is provided in [14].

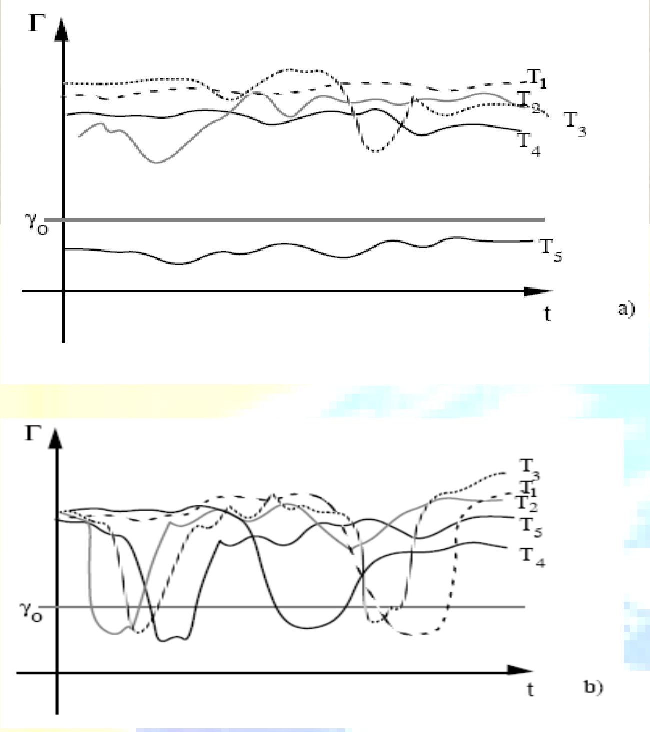

Fig 4 Typical realizations of terminal SIR:s in cellular systems with slowly moving terminals (a) and with rapidly moving terminals (b).

Path loss and interference adaptive schemes will have to "track" (at least slow fading) signal level variations and reallocation rates in the 10's of millisecond range may be required. There is another option of a class of allocation schemes referred as the random channel allocation schemes. The principle is most easily explained using fig 4. The graph 4a) shows a typical set of C/I-trajectories of five terminals in a cellular system. As we can see, 4 of the 5 terminals achieve an adequate C/I, corresponding to an (ensemble) outage rate of 20%. Compare this situation to the one in figure 4b) exhibiting the same outage rate. In contrast to the situation in a) where 2 0% of the terminals are experiencing a low to C/I, here each terminal will experience insufficient quality 20% of the time. In case a) channel coding is a waste of capacity since 4 terminals have sufficient quality and the last unlucky terminal is probably "beyond salvage".

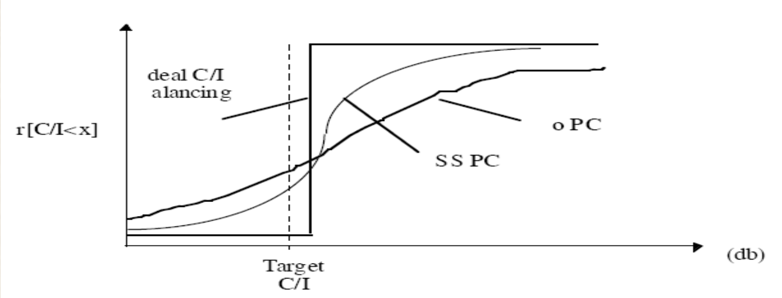

Fig 5 Outage probability minimization - CDF of received C/I

In case b) however, there are probably a sufficient number of reliable channel symbols in all terminals to make reception possible, provided suitable constraint lengths & interleaving is used. The apparent method to achieve the latter situation regardless of the mobile speed is to permute channel allocations in a random fashion. The obvious way is to use (orthogonal) frequency hopping that can be seen as a static channel allocation. In static channel allocation terminals are allocated to a certain access port swap channels with each other [15, 16]. Frequency hopping occurs typically 100-1000 times/second. IS-95 scheme is a cellular phone system based on Direct Sequence CDMA multiple access. Thus multiple users simultaneously share the same (wideband) channel. Designers claim a 20 fold increase in capacity over analog cellular telephony [6]. Effectively, a new random waveform is used for every transmitted bit. DS-CDMA schemes require asynchronous transmission on the uplink but synchronous on the downlink and no cell planning which has made them attractive. Regarding capacity the comparison between DS and FH schemes is not obvious although orthogonal schemes seem to have advantages in mixed cell environments [17]. The performance Comparison of (deterministic) DCA and the Random allocation schemes is very cumbersome and is obviously the more fundamental research topics of the near future.

In certain packet communication systems interference conditions prevails like frequency hopping. Here the packets arrive randomly which triggers transmission events. The proper transmitter power selection in terminals and access port is a separate topic of interest and considerable research is going on nowadays. There are several motives like reducing adjacent channel (cross correlation) interference in non-orthogonal schemes, and to minimize power consumption in order to extend terminal battery life and to control co-channel interference (in schemes with orthogonal waveforms)and hence increase overall capacity of the system. In the resource allocation problem context, it can be shown that the maximum number terminals is supported under a power control (PC) regime that *balances* the C/I of all terminals that can be supported and shuts of the rest[18]. Cellular system under three power control regimes, illustrates why this is so. As we can see, the uncontrolled system exhibits a rather flat CDF with a

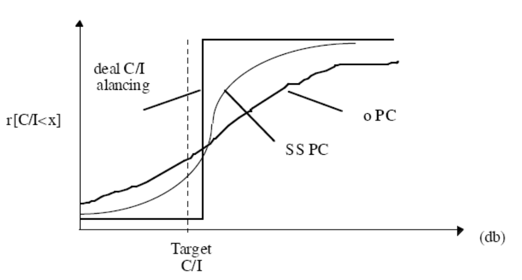

Fig 6, showing the Cumulative Distribution Function (CDF) of the received C/I in an (orthogonal signaling)

high outage probability (at the threshold C/I). A received signal strength based algorithm, e.g. the constant received power scheme, reduces some of the variations in the C/I by limiting the variations in the "C" component.

The figure shows net result of CDF as the variations in the interference part (I) are now larger than earlier. The outage probability is now slightly lower. In the C/I balancing scheme all stations have the same C/I, here slightly over the threshold, leaving only a small fraction of station without support. In order to the design of DCA schemes a closely related problem is finding optimum set of non-supported terminals. Distributed implementations and various implementation constraints [19, 20] have been studied. The findings reveal that very robust, simple and optimum power control schemes can be devised. By using optimum power control, the performance result shows that there is substantial capacity gains (>100%) in static channel allocations. These gains are, of course, not additive with the gains obtained by DCA schemes. However, initial results regarding combined DCA/PC schemes show substantial capacity gains [21, 5].

For packet communication with short messages or in frequency hopping environments, power control as described above may not work properly due to fact that the feedback delay in the power control loop may in fact be longer than the time required to transmit the message (or in FH the chip/burst duration). The instantaneous interference caused by other subscribers makes the problem more complex to accurately measure and predict the C/I. There are several approaches to this problem that have been proposed. In systems utilizing mainly Forward Error Correction, C/I-balancing power control strategies involving estimating statistical parameters of the C/I, e.g. the average C/I (measured over many packet/chip durations) as well as fast C/I estimation/tracking schemes have been proposed[22,23,24,25].

The scenario is quite different in random access systems that utilize retransmissions. Two basic differences between these systems and the continuous ("circuit switched") systems can be noted. Since data traffic is in bursts, and there is greater risk of collisions and during bursty traffic, providing equal transmission quality to all packet transmission (e.g. letting all packets be received with equal powers), turns out to be a disastrous strategy, since collisions forces that no packet can be received properly. It has clearly been demonstrated that a received power spread, such as the one caused by near-far effects or Rayleigh/Shadow fading actually improves the capacity (throughput) of such systems [26]. The findings reveals that power control that creates an even larger power spread can produce even better results [40, 41, 42].

4. Managing mobile networks - the dynamics of resource allocation:

Due to mobility of active terminals in the service area, the propagation delays and interference situation may lead to a situation that the terminal cannot be supported by the same channel. New terminals may enter the service area requiring services, some active terminals may be moving outside the service area while others are terminating their communication sessions. Mostly, the basic resource allocation schemes described above are best suited for static or quasi-static situations that are encountered on a microscopic, short term, time scale. Hence, we need to evolve a suitable resource management schemes that handles these mobility issues. In mobile networks, where there is link quality variations due to terminal moving during an active session some kind of resource reallocation may become necessary.

Maximizing the instantaneous received signal level may, however, not be neither very practical nor produce the best results. In microcellular networks systems, the coverage areas of the base stations overlap to a large extent. Mostly, low signal levels may not be a problem since normally several base stations provide sufficient signal levels. In such situations usually the variations in the interference causes a handoff rather than cell boundary crossings. Whenever there is overlapping coverage area amongst the several base stations providing sufficient C/I, the system is also able to handle traffic variations by means of *load sharing,* i.e. by letting less loaded base stations support terminals even though they are providing less C/I than the best (often the closest) port [30]. Different permutation and combinations of power control and channel selection also show promising results [31, 32]. It is due to overlapping cells that soft handoff schemes are being extensively studied rather than conventional handoff schemes [33]. Keeping track of the exact position of the mobile terminals in a large (possibly global) wireless system is a very cumbersome task. Although this is handled mainly on the fixed network end, there are important implications to the resource management. The trade-off between the capacity required for the air signaling to monitor the whereabouts of the terminals (the "locating" procedures) and the capacity required for finding, or paging, a terminal when a communication request comes from the network end, has received quite some attention[34,35] in CDMA schemes. Handling arriving and departing terminals poses a slightly different problem. Whenever there is request for a new call or handoff call the RRA system has to take decision to accept or reject call request into the system. The admission control algorithm makes these decisions on the basis of availability of resource and prevailing conditions in the system. The efficiency of an admission decision may not be estimated beforehand without physically executing the admission itself *as* it is an uphill task to monitor the exactly the traffic conditions and linked quality at all times. The admission procedure may fail in two ways I: (“False admission”) A terminal is admitted giving rise to a situation where one or more active sessions cannot be supported (not necessarily including the admitted terminal).

II: (“False rejection”) A terminal is rejected when successful resource allocation actually was possible.

In dynamic channel allocation or random allocation schemes, the resources are kept in a central pool and are allocated as soon as there is a call in any cell. There is no clear limit on number of channels/waveform that can be used by a cell. These are called “interference-limited” systems as allocation of a channel is limited by the current interference situation. Particularly, in systems utilizing C/I-balancing power control this is complicated by the fact that already active terminals will react to the admission of a new terminal by adjusting their transmitter powers. Therefore it is very much possible that the admission of yet another new subscriber may disturb several or sometimes all of the original users at the required C/I-level. There are two categories of Admission control schemes namely *non-interactive* schemes and *interactive schemes* [36]. The non-interactive schemes proposed are mainly using different types of interference or transmitter power thresholds [36], i.e. when the measured interference (or the currently used power) on some channel (cell) is too high, admission is denied. The interactive schemes involve the gradual increase of the power of new terminals until they are finally admitted. Such a procedure to protect the already established procedure connection is referred to as “Soft-and Safe (SAS)” admission [37] or channel probing/active link protection [38].

5. Resource allocation issues in Future Systems:

The early systems were designed basically for carrying circuit switched traffic (e.g. speech, low rate circuit switch data) rather than packet switched traffic (e.g. data/multimedia, high rate packet switch data). Let us look into some of the more important features of the traffic expected in future systems that will impact future system design in general and on radio resource management in particular.

5.1 High bandwidth

In the years to come, the demand for higher data rates than present systems is very much expected. There is a continuous improvement in hardware required for higher data rates. The newer applications demanding higher bandwidth are being generated. In 3G wide area personal communication systems (cf. UMTS, FPLMTS) data rates in the range 64 kbit/s - 2 Mbit/s are discussed. In local area networks speeds beyond 10 Mbit/s are common practice. Even radio access at ATM (155 Mbit/s) rates has been discussed [39]. Data rates in personal communication systems are certainly limited by propagation conditions as multipath etc., but the primary constraining factor is the quality of link [40].

The increase in bandwidth as such does not affect very much the design and performance of RRM algorithms. In fact, much of the control signaling required by many of the adaptive schemes will, occupy a smaller fraction of the available bandwidth. Increasing the infrastructure density, with more base stations, will apparently adds to complexity of the RRM algorithms. The emphasis on distributed schemes will be even more pronounced in these systems.

5.2 Non-uniform data traffic

The traffic characteristics play a major role in the design and performance of RRM algorithms. In particular data traffic, but also speech and file transfers, can be seen as discontinuous streams of symbols. There are two main problem areas involved:

• Delay constraints

Circuit switching systems are normally designed for voice communication (that generates uniform traffic) and to meet absolute delay constraints, whereas the delay for data traffic (generates bursty traffic) normally is constrained in the statistical sense (e.g. average delays). Hence data traffic provides an additional flexibility in the resource allocation procedure leading to better resource utilization. There is trade-off between blocking and additional delay. This has lead to the design of radio access schemes particularly designed for delay non-sensitive, very "bursty" traffic, which is called packet radio system. In these systems there is no time for the exchange of resource allocation information because messages are short and delay is to be kept low.

• Insufficient information

Systems with bursty data transmission will also face from a different set of problem. Since there are no continuous transmissions, quality of link cannot be estimated at will but only when there actually is a transmission in progress. In particular when the traffic is very sporadic the statistical estimates of the link-quality parameters can degrade considerably since the terminal may are mobile and can move a considerable distance between transmissions. This affects all type of RRM decisions, e.g. channel allocation, power control and hand-off decisions. In these situations channel allocation decisions and power control has to be made on estimated average link qualities rather than on instantaneous values. In these cases, the concept of a "hand-off" looses it meaning in the physical sense and one may instead consider different "connection-less" (or multiport) schemes where any base station in some area may receive messages from a mobile terminal without the explicit establishment of a logical/physical connection [30, 31].

5.3 Mixed traffic

The key problem in “multimedia”-type system is the data rates and delay constraints traffic in small cell environments will show very zigzag traffic conditions at average capacity demands. Real time applications such as streaming audio/video with absolute delay requirements may require considerable portions of the spectrum which they share with email-type message traffic with no such absolute constraints. Dynamic spatial resource reuse has the potential of broadening the traffic basis for efficient use of spectrum resourced and it is very importance [41].

An adverse effect of this is, however, that also the interference experienced by different users will show the same wide span in character [42]. In particular if we would like to estimate the link quality for a high quality circuit switched service, the link will be subject to both quasi-constant as well as irregular interference (from packet service users). For reliable estimation of the C/I as a basis for RRM decisions, will be an uphill task to handle.

6. Conclusions & Discussion:

We have tried to present a radio resource problem formulation based on the three basic resource allocation decisions: channel, base station and transmitter power. These three are closely inter-related.

Traditionally we consider efficient sharing of the frequency spectrum resource to enhance the capacity of the system. Since there is no any upper limit on the user population that can be served and it is important that we widen the resource allocation and management perspective. Factors like more dense hardware infrastructure costs and terminal power consumption play critical roles. The trade-offs such as where the signal processing load should be put in a wireless system - in the terminal where power is scarce or in the fixed infrastructure, can be easily visualized. The key question here is: Should the access port infrastructure be very dense (and costly) allowing for "dumb", cheap, low power terminals or should terminals be more complex allowing for the rapid deployment of a cheap infrastructure at the expense of battery life and terminal cost ?

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