Dimensioning of Hierarchical B3G Networks with Multiple Classes of Traffic

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Abstract

Dimensioning of mobile networks (e.g. 2G, 3G, WLAN etc.) is more or less restricted to the service area projection and wireless capacity formulation (calculation of number of base stations/access points (BSs/APs) required) in supporting the anticipated traffic load. As the Beyond Third Generation (B3G) network promises to provide inter-connectivity among all existing technologies with minimal software and hardware upgrade, any significant change to coverage area and capacity of existing networks will violate this key promise. To adhere to the B3G definition, in this paper we have proposed a dimensioning framework that is confined to the wired part of the network and will support wide area coverage (typically for high speed subscribers) in the presence of multiple classes of traffic. The framework derives an initial estimate bound of wired network elements (i.e. number of BSs per AR, number of ARs per MAP and number of MAPs per GW) in a multi-tier hierarchical system based on user capacity limits (soft-capacity), future traffic projection and mean traffic load (or average data rate) for each class of traffic. Simulation results demonstrate the wired network bound under different traffic distributions and for bounded average cell capacities (soft-capacity).

1. Introduction

Access networks are deployed and optimized for different services that have their own set of characteristics (average bit rate, bandwidth etc.) and grade of service requirements (E_b/N_0, delay, SNR etc.). For example 2G network has been optimized for voice traffic, while 3G (backward compatible to 2G) and WLAN offer high speed/high bandwidth data services. The dimensioning and subsequent deployment of each of these networks in principle follows the methodology adopted in 2G networks which is largely based on a tedious trial and error process [1]. This involves calculating the required number of base stations (BSs) upon the projection of service area and maximum allowable cell loading, and their successful deployment. In the deployment phase, an expert radio planner manually selects sites to host a BS, specifies propagation model and service requirements, and analyzes the measurement data taken around the BS over various instances of time. If the results do not meet the QoS requirements (e.g. blocked calls, cell loading etc.) of the service then either changes are made to the BS parameters (transmit power, SNR, antenna tilt and azimuth etc.) or else the BS is moved to a new site and the entire process is repeated. Subscriber growth is addressed by adding new network elements (e.g. new cell sites or reduced cell sizes) to the initial dimensioning estimate in order to satisfy the increased traffic.

Since the Beyond Third Generation (B3G) networks epitomize on evolution rather than revolution by interconnecting all existing and emerging access technologies through a common IPv6 core network, the dimensioning process involved will be notably different from conventional networks. This is because any significant change to the radio network (coverage area and capacity) of existing technologies will violate the B3G definition of inter-connectivity. As a consequence the dimensioning process will largely be confined to organizing the wired network elements in a structured way guaranteeing minimum QoS.

Unfortunately extensive literature review has revealed a dearth of dimensioning work in B3G networks, in particular for the wired segment. Most of the research work so far has focused on the wireless dimensioning aspect of existing networks i.e. the cell coverage (in km) and required capacity (e.g. number of BSs) once the system area (in km^2) and maximum allowable cell loading (either in Mbps or Erlangs) is determined [2-4]. Few of the works that have addressed core network dimensioning include [5] which describes a GUI based forecasting tool albeit in a fixed channel environment. Furthermore the legacy networks mainly consider single class of traffic (e.g. poisson distributed voice call arrival) during the dimensioning process. Even when multiple classes are considered as in 3G WCDMA network, calculations are oversimplified by adopting a single class traffic approach [6]. The cell loading and subsequent planning which results from such single traffic approach therefore do not reflect the statistical characteristics of other traffic

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distributions. For example, multimedia can be modeled as an autoregressive process while data traffic can be modeled as self-similar traffic with long range dependence exhibiting burstiness over different time scales. Unfortunately analytical expression for cell loading based on different traffic distributions is difficult to derive, leading to the adoption of average characteristics of multiple traffic profile to simplify the calculations. The network designers need to consider these issues in the dimensioning process and the ensuing deployment stage of the B3G network. In this paper we have therefore proposed a framework that predicts a bound on the wired part of the hierarchical B3G network architecture [7] taking into consideration multiple classes of traffic profile. The hierarchical architecture, constituting of tiers of base stations/access points (BSs/APs), access routers (ARs), mobility anchor points (MAPS) and gateways (GWs), offers: localized handoff enabling wide roaming facility to dormant terminals without initiating registration, faster connectivity and data transfer between adjacent domains etc. The proposed algorithm offers an approximate solution to the analytical expression problem by adopting the average traffic profile of multiple services and provides an initial estimate of network elements (including number of BSs per AR, number of ARs per MAP and number of MAPs per GW) based on the future traffic projection and the mean traffic load (in Mbps) per traffic class. As cell loading relies on the user capacity in the underlying network, the soft-capacity in CDMA based networks (determined by the bandwidth and power limits of the BS in the forward link and mobile terminals in the reverse link [8]) far outweighs the fixed capacity of 2G networks. The proposed dimensioning algorithm in this paper reflects this very point by considering soft-capacity in an interference limited (reverse link) 3G cell (alternatively in a WCDMA based cell) as the deciding factor along with future traffic projection and mean traffic load (average data rate) for each class of traffic in deriving the network bounds of a B3G network.

The paper is organized as follows. Section II provides a brief overview of the hierarchical system structure. Section III explains the proposed dimensioning algorithm while Section IV shows the simulation results. Conclusions are drawn at the end of the paper.

2. Hierarchical System

Fig. 1 shows the proposed hierarchical and modular B3G network with distributed system architecture [7] and different link capacities. Within a domain, the lowest tier is formed by overlapping BSs/APs from different underlying access technologies and is controlled by an AR. All subscribers within a domain access services through the MAP. The gateway (GW) connects multiple MAPs to offer faster connectivity and data transfer during inter-domain handovers. As shown in Fig. 1, the MAP is connected to multiple GWs and the core network via several wired links. Since significant amount of data transfer takes place between adjacent domains, multiple links assist in distributing this traffic among several GWs thereby alleviating the network response time. GWs not only enhance inter-domain communication, but during heavy load condition when the direct link from the MAP to the core network is near saturation, they provide remote data transfer facility as well. A distributed Bandwidth Broker (BB) based architecture is adopted to carry out resource management and resource negotiation within the domain and along the communication path between peer end terminals [7]. Although each AR at the edge of the hierarchy is capable of becoming a BB, MAP offers the best choice to take on the role of a BB. Management of each domain is carried out by an administrative body and service agreement is assumed to exist among different network providers.

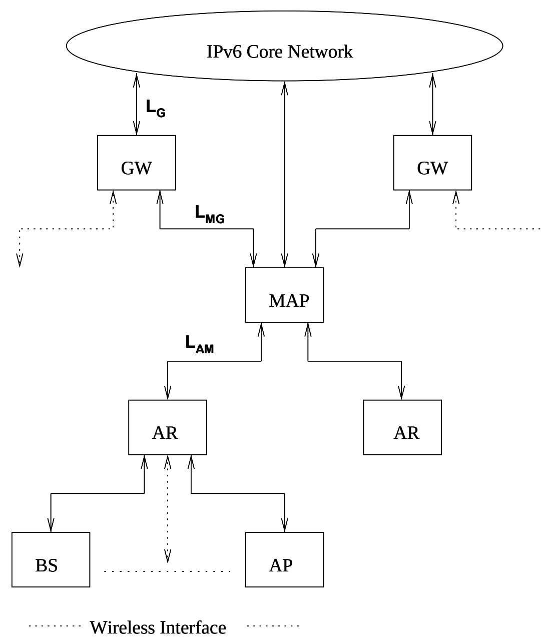

Figure 1. Multi-tier hierarchical system architecture

Since B3G network will be expected to offer ubiquitous mobility, to support high speed subscribers (in vehicles) in addition to stationary and pedestrian ones, the service area will have to incorporate the macrocell approach which offers wide area coverage. The proposed algorithm therefore considers macrocells in its dimensioning of wired network elements. Once the initial estimate is derived, smaller cell sizes (microcells, picocells etc.) can be considered to compliment the wide area coverage. The following section describes the proposed algorithm in detail.

3. Proposed Dimensioning Algorithm

Cell loading is closely associated with the average cell residence rate and call arrival process. With different probability distributions modeling different classes of traffic arrival (e.g. voice, data, multimedia etc.), analytical approach to formulate aggregate cell loading in B3G network soon proves to be intractable necessitating the adoption of an alternative approach (considers average traffic profile). Suppose that there are k classes of traffic in the network: k =1, 2, 3…, K. Assuming uniform distribution of average cell residence rate, the rate for k classes of traffic in cell i is given as, $N_i = (N_{1,i}, N_{2,i}, \ldots, N_{K,i})$. If the mean traffic load/data rate for k classes of traffic is, $R = (R_1, R_2, R_3, \ldots, R_K)$ then the average traffic capacity in cell i can be written as,

$$T_i = \sum_{k=1}^{K} N_{k,i}.R_k \text{ , } i=1,2,3\ldots M \text{ cells.}$$

Average Cell Load Calculation: As mentioned earlier, in the proposed algorithm a macro-cell based approach (wide area coverage) is utilized where the cell radius is derived from [9]. Reference [9] dimensions a B3G network in the presence of voice traffic only to ensure that the infrastructure has sufficient number of elements to handle at least voice service whenever there is an outage of other services. It can be seen from [9] that in a B3G network the maximum cell radius (macrocell) achievable with a Walfisch-Ikegami model (WIM) for a certain QoS (E_b/N_0=5 dB) is 2.5 km. With such a cell radius, the signal power from the mobile terminal will diminish significantly as it reaches the serving BS in the presence of path loss and log normal shadowing. In order to maintain the desired SNR at the BS, closed or open loop power control is used to regulate the terminal transmit power so that signals from all terminals within the cell coverage area arrive at the BS with equal power. Since CDMA cell capacity is coverage limited (usually in the reverse direction) as well as being interference limited, we calculate the minimum allowable received power to achieve the target E_b/N_0. Terminals near the edge of the cell will be the most affected by the propagation channel impairments. Therefore in our calculation of minimum received signal power we consider the transmit power from this distant terminal as,

$$S_r = 10^{\xi/10} d^{-4} S_t \tag{1}$$

where S_r is the received signal power, S_t is the maximum allowable transmit power (terminal), d is the cell radius and ξ is a zero mean Gaussian random variable with standard deviation of around 8 dB. Since cell loading in CDMA based networks are governed by interference in the reverse link, total interference at the BS needs to be estimated before capacity can be determined. With multiple classes of traffic, individual traffic profiles are required to calculate the aggregate cell loading. The received signal power from (1) and *a priori* knowledge of expected E_b/N_0 for each class of traffic enables the calculation of maximum interference level for the k-th traffic and is given by,

$$I_k = \frac{S_r \dfrac{w}{a_k.R_k}}{\left(\dfrac{E_b}{N_o}\right)_k} \tag{2}$$

where I_k is the total interference, w is the chip rate, R_k is the data rate, a_k is the activity factor and $(E_b/N_0)_k$ is the bit energy to noise density ratio of the k-th traffic.

The total interference pertaining to each class of traffic defines the upper and lower threshold of interference which are given by $I_{th,low} = \min(I_k)$ and $I_{th,up} = \max(I_k)$: k =1, 2, 3,…, K. These interference thresholds then enable the calculation of the user capacity per cell as follows,

$$(N_i - 1)S_r + \eta'(N_i - 1)S_r + \eta = I_{th,x} \tag{3}$$

where the first term is intra-cell interference, the second term is inter-cell interference governed by the loading factor η' [9] (η' is a factor between 0% and 100% representing percentage increase of interference from neighboring cells above those introduced by intra-cell users only) and the third term is background noise, while $I_{th,x}$ denotes the interference threshold level. Hence from (3) the lower cell capacity can be written as,

$$N_L = \frac{I_{th,low} - \eta}{S_r(1+\eta')} + 1 \tag{4}$$

and higher cell capacity is given as,

$$N_U = \frac{I_{th,up} - \eta}{S_r(1+\eta')} + 1 \tag{5}$$

The average cell residence rate (uniformly distributed in the entire network) is therefore bounded by (N_L, N_U).

Network Dimensioning: It is expected that by 2010, 80% of the total traffic will be data (real-time as well as non-real time packet traffic) while only 20% will be voice traffic. Assuming uniform traffic distribution throughout the network, each cell traffic will have the following distribution, $p = (p_1, p_2, p_3, \ldots, p_K)$: $\sum_{k=1}^{K} p_k = 1$. Based on the average cell residence bound (N_L, N_U) from (4) and (5), traffic distribution from above and mean traffic load (or data rate) for each class of traffic, the soft-capacity of a BS in cell i can be calculated as,

$$C_{BS,ix} = \sum_{k=1}^{K} p.R_k.I_{th,x} = \sum_{k=1}^{K} R_k.T_{th,x} \tag{6}$$

where $T_{th,x}$ denotes the average traffic bound in cell i. Here we consider that all the BS capacities within the network are bounded by this soft-capacity limit.

Assuming fiber optics to replace existing wired links so that more connections can be accommodated via for example wavelength division multiplexing (WDM) thereby offering high data transmission rate in the wired backbone, the following links, differentiated by their capacity, are considered in the proposed algorithm (shown in Fig. 1).

L_{AM} =link between AR and MAP =622.08 Mbps (optical carrier (OC)-12)
L_{MG} =link between MAP and GW=1.244 Gbps (OC-24)
L_G=link between GW and the core network=2.488 Gbps (OC-48)

With technology improvement in CMOS design, higher speed links may become available that will be able to replace the abovementioned ones. Using these OC links the number of BSs per AR can be deduced as,

$$n_{BS} = \frac{AR\_link\_capacity}{BS\_capacity} = \frac{L_{AM}}{C_{BS,ix}} \quad (7)$$

Now each MAP has a total of l links to GWs and the core network where each of the links is denoted by L_{MG}. Based on the total capacity of a single MAP, the number of ARs per MAP can be calculated as follows,

$$n_{AR} = \frac{MAP\_link\_capacity}{AR\_traffic} = \frac{L_{MG}.l}{n_{BS}.C_{BS,ix}} \quad (8)$$

Assuming that β fraction of the total traffic from a MAP goes to multiple GWs while (1-β) fraction goes directly to the core network, number of MAPs per GW can be calculated as,

$$n_{MAP} = \frac{GW\_link\_capacity}{Fraction\_MAP\_traffic} = \frac{L_G}{\beta.\frac{n_{AR}.n_{BS}.C_{BS,ix}}{l-1}} = \frac{L_G}{\beta.\frac{L_{MG}.l}{l-1}} \quad (9)$$

where $\beta.\frac{L_{MG}.l}{l-1}$ represents the average traffic sent to a single GW from each MAP.

4. Simulation Results

Table 1 summarizes the parameters used in the proposed dimensioning algorithm. The focus here is on calculating an initial estimate bound of wired network elements offering wide area coverage. This is reflected on the choice of data rate for the three classes of traffic considered, especially data and multimedia traffic with respect to mobile subscribers (possibly in vehicles). Simulations are carried out over the upper and lower limit of average cell residence rate (in this case 16 and 154 users per cell) for a cell radius of 2.5 km. Fig. 2 and 3 show the wired network element bounds for different traffic distributions and link choices. Here traffic distribution signifies variation of voice traffic in comparison with data and multimedia traffic. The voice traffic is varied from 100% to 20% as per the future traffic projection. It can be seen from Fig. 2 that as the data and multimedia traffic starts to dominate voice, the number of BSs per AR (l =3) decreases, taking into consideration the higher data rate and E_b/N_0 requirements. The choice of the required number of BSs per AR will rely entirely on the network provider, bounded by the extremities shown in Fig. 2. The issue of monetary cost and provider's own traffic projection will subsequently dictate this choice.

Table 1. Simulation parameters

Traffic class, k	Voice, data, multimedia
Cell radius, d	2.5 km [9]
Mobile Transmit power, S_t	1 watt
Chip rate, w	3.84 Mchip/s
Bit energy to noise density, $\left(\frac{E_b}{N_o}\right)_k$	5 dB, 1.5 dB, 5 dB [11]
Mean traffic load (data rate), $(R_b)_k$	12.2 Kbps, 144 Kbps, 64 Kbps [6, 10]
Normal random variable, ζ	Standard deviation: 10 dB
Activity factor, a_k	0.5, 1, 1 [6, 11]
Background noise, η	-103 dBm [12]
Loading factor, η'	30%
Fraction of MAP traffic, β	50%
Average cell residence rate	Lower limit: 16 (N_L) Upper limit: 154 (N_U)

Fig. 3 on the other hand shows the selection of number of ARs per MAP and number of MAPs per GW as l is varied with 20% voice traffic projection. It is evident from the figure that l has a profound effect on the number of ARs per MAP with lower residence rate. This is because with finite link capacity (L_{MG}) lower residence rate allows more ARs to be included under the same MAP as l is varied while with a higher residence rate the cell loading quickly converges to the maximum limit. We can also see from Fig. 3 that as l increases so does the number of MAPs per GW with lower residence rate because the MAP can distribute the adjacent-domain traffic more equitably among increased number of GWs thus allowing higher number of MAPs to be included under the same GW. At higher residence rate the traffic under each MAP converges to the maximum limit and hence the choice of number of MAPs per GW is affected entirely by the links l whereas the choice converges to a value of 3 at lower residence rate.

When deploying the B3G network the onus will therefore be with the network providers to choose the number of wired network elements in addressing the projected traffic load within the aforementioned bounds. Proper selection of the wired links will be the key to meeting this traffic.

5. Conclusions

B3G network is envisaged to glue together all existing and emerging access technologies through a common IPv6 core network. Since it will be an evolutionary step from current networks rather than a revolutionary new technology and would involve minimal software and hardware upgrades, significant changes to the existing cell coverage and capacity will violate the key promise of inter-connectivity. Therefore the dimensioning of B3G network will largely involve restructuring the hierarchical system through proper selection of wired links. In this paper we proposed a dimensioning framework that derives the upper and lower bounds of wired network elements i.e. the number of BSs per AR, the number of ARs per MAP and the number of MAPs per GW, in the presence of multiple classes of traffic. Future traffic projection (data traffic including multimedia dominating other traffic classes) and mean traffic load (or data rates) are utilized in deriving the average BS capacity (cell loading) bound. The CDMA based soft-capacity that governs the cell loading in the proposed algorithm is calculated from an interference threshold based mechanism. The simulation results presented at the end of the paper offer the network providers with an estimate of the wired network elements that would be required during the deployment phase of a B3G network.

6. References

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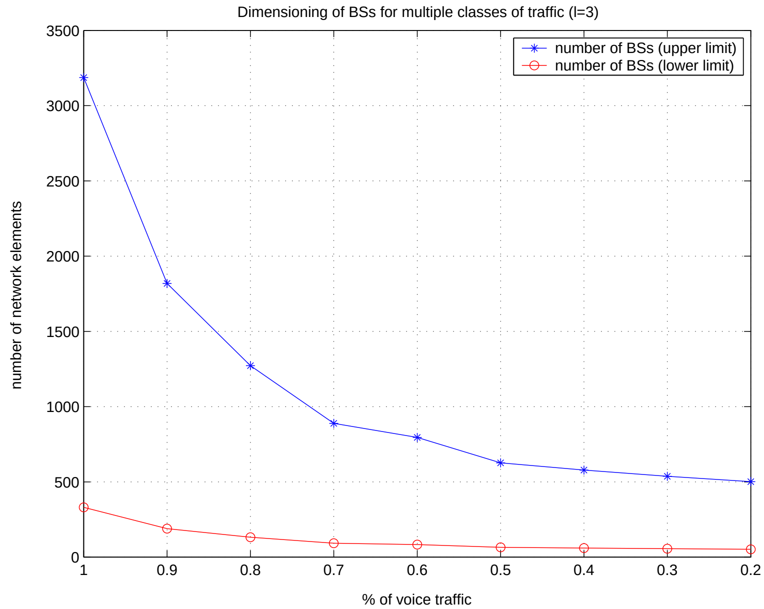

Figure 2. Selection of BSs per AR for different traffic projections

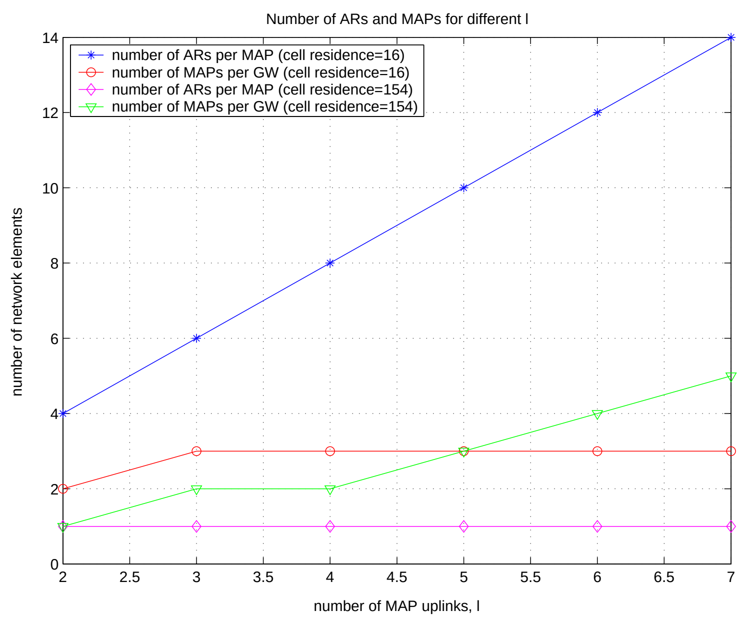

Figure 3. Selection of ARs per MAP and MAPs per GW for varying numbers of *l* at 80% data traffic projection