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Invited paper

Teletraffic issues in mobile communication network planning

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In this paper we present an overview of the application of teletraffic methods for the planning of mobile communication networks. It is shown that there is a necessity for an accurate description of the spatial traffic in order to perform a demand based planning. To accomplish this task, a new traffic demand characterization concept based on a pattern of discretized demand nodes is presented. The spatial traffic distribution also plays an important role when designing networks according to new emerging standards like UMTS. Here, novel analytical models for performance evaluation are required, whether for the examination of the interference limited system capacity or the impacts of variable bit rate voice coding on the transportation over the interconnecting fixed network structure. It is also shown that a spatial characterization of the demand facilitates the application of discrete algorithms for locating base stations.

1. Introduction

Due to today's tremendous customer demand and rapid growth of mobile networks, with more and more carriers joining the market, the need for a systematic planning methodology has become essential. Furthermore, knowledge about customer behavior and measured traffic data have become more accurate to allow for detailed planning procedures. In conventional cellular planning emphasis is mainly laid on the radio planning aspects, i.e., selection of cell sites, frequency planning, and antenna design, which can be found in the majority of todays cellular network planning tools. The major disadvantage of this approach is that it focuses almost exclusively on radio design aspects of cellular network planning while leaving considerations of teletraffic issues and customer behavior aspects out of scope.

The aim of this paper is to discuss the importance of teletraffic issues in mobile network planning and present an approach to characterize customer demand and incoming traffic using a partitioning algorithm, the concept of discretized demand nodes [17]. This results in a 2-dimensional representation of quasi-stationary offered traffic, which forms a basic requirement for traffic-oriented mobile network planning. The need of spatial traffic considerations is also demonstrated taking into account the elastic nature of coverage areas in CDMA [13] or the future Universal Mobile Communications System (UMTS).

An integrated planning approach as proposed in [15] copes with the previously mentioned shortcomings. In contrast to the conventional approach where the planning process is driven by area coverage considerations, this approach is driven by the customer demand. The aim is not to cover as much area, but to supply as many users and their traffic demand as possible. Additionally, existing interactions between planning constraints are taken into account when resolving conflicting planning objectives. By doing so the approach automatically obtains planning solutions which are optimized under multiple aspects. The key concept to achieve this is the introduction of *demand nodes*. A demand node represents the center of an area with a certain teletraffic demand. The definition implies that the demand nodes are dense in areas of high demand and sparse in areas where demand is low. One of the key components of the system model for network performance analysis is thus a model of the demand node pattern.

There are several ways to generate a spatial demand node distribution pattern. One way is to use a clustering algorithm like the one described in section 3, by using traffic data from measurements, where a mapping can be done to estimate the impacts of some parameters in the available data (like land usage, population structure) on the traffic demand. For analytical computation purposes, abstract models can be employed to generate a point pattern in a purely mathematical way by using a spatial point process. In [8] a spatial phase-type process is presented that can be considered as a generalized case of the well known homogeneous spatial Poisson process. Another example is the spatial BMAP process in [1] which has a very appealing feature of being able to include a time-dependent evolution of the process.

As mentioned above the customer behavior has to be taken carefully into account. This includes also the modeling of the customer behavior dealing with the call retrial phenomenon. In [11] two models are presented. The first model considers a base station with a finite customer population and repeated attempts. A Markov chain modeling is proposed and a recursive solution of the state probabilities is presented. The second model focuses on the use of the guard channel concept to prioritize the handoff traffic. Again the retrial phenomenon plays an important role on the quality of service experienced by the mobile customers [12].

The planning process of cellular systems requires a careful consideration of the wireless parts concerning the optimal locations of the transmitters, as well as a proper dimensioning of the fixed network components which will carry the traffic from the base stations (BS) to the switching centers and further network components. Future mobile communication systems like UMTS or IMT-2000 show that CDMA technology will dominate the transmission part of the access network. In CDMA systems, voice is encoded and packaged in variable length packets that are transported between the mobile station and the switching center. While the packetization provides a great flexibility in resource allocation, it poses a *quality of service* (QoS) problem on the voice transport task. A degradation of the QoS can be avoided by a proper dimensioning of the used link between the CDMA base station and the mobile switching center. In [4] a T1/E1 link as BS-MSC interconnection is examined in order to satisfy the quality of service in terms of delay bound (maximum allowable delay) and packet loss probability. It is shown that for almost all practical link speeds, statistical multiplexing provides a reasonable gain over peak rate allocation (or circuit switching). This work is continued in [3], where the efficiency of using an ATM link for connecting the BS to the ATM core network was assessed. Owning to the low bit rate of the IS-96 voice coding employed in the IS-95 [10] system the ATM Adaptation Layer Type 2 (AAL-2) is considered appropriate for tunneling vocoder traffic. The results show that with typical T1/E1 bandwidth AAL-2 multiplexing is only capable to transport about 80% of what the unchannelized raw T1/E1 link can handle. Nevertheless, with ATM it is possible to adapt the bandwidth of the BS to core network connection to current load conditions of the cell.

This paper is organized as follows. Section 2 deals with the description of clustered customer traffic using 2-dimensional representation of point patterns. It is shown that for the planning of mobile communication networks, it is necessary to describe the teletraffic of the observed area using 2-dimensional point patterns. Section 3 will present methods how to perform such a traffic characterization and how this can facilitate cellular network planning. The algorithms described in that section have been implemented in a realistic commercial network planning tool ICEPT [16]. While demand based planning is important for any wireless network, it is extremely the case for networks applying CDMA technology. This is due to the fact that here cell capacity is interference-limited and each user contributes to the total interference in the cell. Section 4 shows how this probabilistic nature of the user distribution and cell coverage can be used in the planning process of CDMA networks. Section 5 concludes this paper and gives an outlook on future projects.

2. Two-dimensional traffic process and subjective quality of service

One of the key components for network planning is of course the performance of the planning solution itself. As in wire-line telephone systems, a typical evaluation task in mobile network planning is based on the following steps (cf. figure 1):

1. *Measurements in real systems.* Typical measures for traffic process modeling are customer population and distribution as well as mobility profiles of mobile stations.
2. *Teletraffic process description.* Based on the measured data, a 2-dimensional traffic distribution can be chosen to represent the customer population and its distribution.
3. *Use of input process in performance models.* Analytic and simulative process descriptions must be usable as input processes of performance models of mobile networks.

An important question in mobile network planning that remains to be answered is how does the structure of the traffic distribution affect the performance of a cell in particular, and the entire network in general. For this, we consider the *subjective quality of service*, i.e., the QoS experienced subjectively by a test customer (TC) being in a cluster structure. We can define the subjective QoS as the call blocking probability

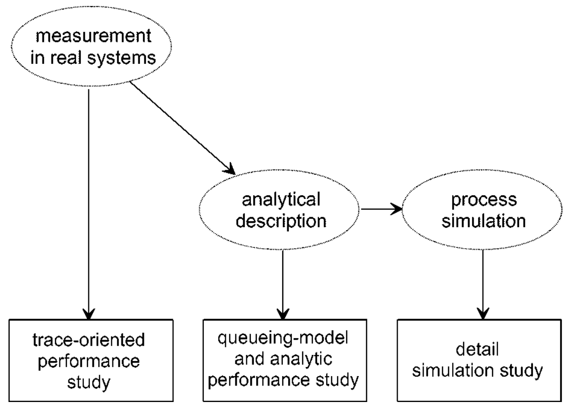

Figure 1. Methods for performance evaluation.

experienced by the arbitrary test customer in the observed area. If the TC is located in a clustered geographic environment and the network planning does not take into account this customer concentration, the subjective QoS experienced by this customer will decrease. As will be seen later, this issue turns out to be extremely important when dealing with networks with CDMA technology.

2.1. *Modeling of subjective QoS versus cell design*

We can now observe a TC in a mobile network with the traffic distributed in a clustered structure. In this environment, an omni-cell covers and supports a number of customers. The cell covers area F, to which a constant number of K channels are allocated. Due to the cluster structure, the number of customers in an observed area is random. The customer traffic process is embedded in a finite source model as shown in figure 2. This model of a cell is a standard loss system with K servers and a finite number of sources X. In this case X is a random variable representing the population of customers randomly accounted in F. This customer population is obtained, e.g., if we position a cell of size F independently, i.e., without taking the cluster structure into account.

2.2. *Clusters and subjective QoS*

We define the subjective QoS as the call blocking probability seen by the arbitrary TC. With $x(i) = P(X = i)$ the probability $x^*(i)$ of the TC to be in a cell with population $X = i$ becomes

$$x^*(i) = \frac{i\,x(i)}{E[X]}. \tag{1}$$

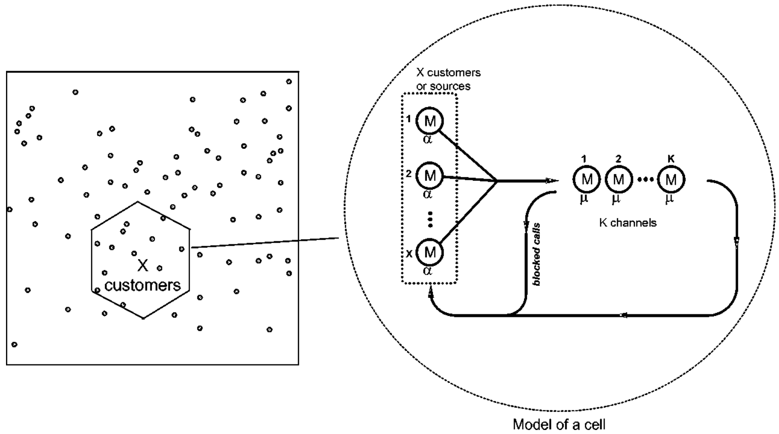

Figure 2. Omni-cell with customer clusters.

Applying the well-known Engset formula leads to the conditional blocking probability of the test customer being in a cell of population $X = i$,

$$p_{\mathrm{B}}(i) = P\big(\{\text{test customer rejected} \mid X = i\}\big) = \frac{\binom{i-1}{K}(\alpha/\mu)^K}{\sum_{k=0}^{K}\binom{i-1}{k}(\alpha/\mu)^k}. \tag{2}$$

Taking equations (1) and (2) together, we arrive at the blocking probability of an arbitrary test customer, which is also the subjective QoS described above

$$p_{\mathrm{B}} = \sum_{i=K+1}^{\infty} p_{\mathrm{B}}(i)x^*(i). \tag{3}$$

Figure 3 shows the subjective QoS for a cell with $K = 7$ channels. The expected number of customers within a cell was chosen such that assuming $\rho_M = 50$ mErl of offered traffic per customer leads to a QoS of 0.1% for a constant number of customers in the cell. It can be seen that the difference between the deterministic and Poisson case is quite small. However, the QoS largely degrades when assuming that the customer population in a cell follows a negative-binomial distribution. Consequently, it is not sufficient to fit the model by means of the first two moments of the customer population only. The type of the distribution has also to be taken into account.

While [11] only considers different distributions of Poisson or negative-binomial customer population in the observed cell, it is also possible to obtain a distribution from real world traffic measurements. Since each realistic traffic distribution obtained from measurements is unique, it is often not possible to simply use a Poisson or negative-binomial customer population, but to use the data obtained from measurements, see figure 3. Figure 4 shows the spatial traffic distribution of demand nodes generated with a method which will be introduced in the next section. It shows a 160 km $\times$ 160 km area around the Dallas–Fort Worth metroplex in North Texas. The input for

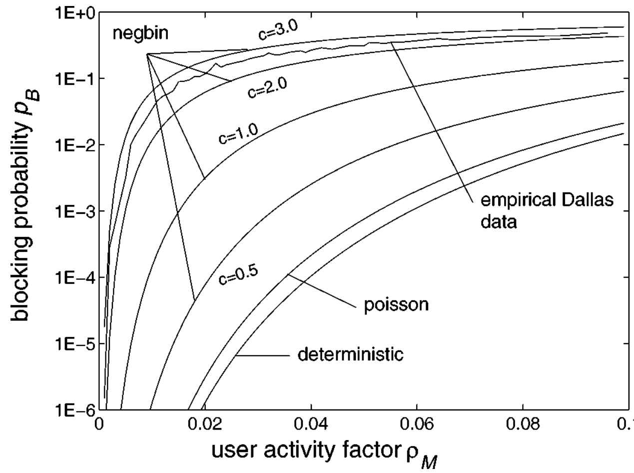

Figure 3. Impact of clustered customer population on subjective QoS.

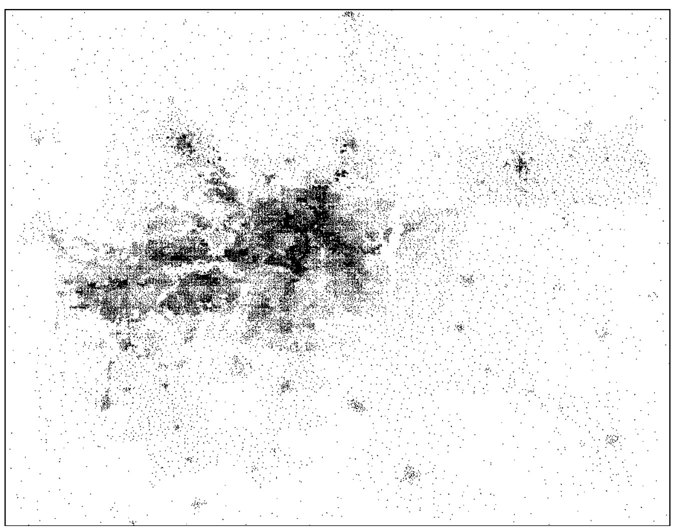

Figure 4. Two-dimensional demand node distribution of the Dallas–Fort Worth area.

this point distribution was generated by a traffic matrix obtained from measurements. As can be clearly seen, the pattern is of a very clustered nature. The areas around downtown Dallas and downtown Fort Worth show a much higher traffic intensity, indicated by the much higher density of points, than the areas of the surrounding smaller cities or suburbs. The following section deals with algorithmic methods to obtain a 2-dimensional demand node distribution, when the traffic of the observed area is known or if this is not the case to approximate the traffic matrix on the basis of known data and its impact on traffic. Section 3 will also show how this demand node distribution is useful for network planning.

3. Customer traffic estimation and characterization

Designing modern telecommunication networks has become a very demanding engineering task. Large scale mobile communication networks with nationwide coverage are encompassing thousands of radio transmitters and hundreds of controllers and switching facilities. An efficient configuration of such large scale systems can only be obtained by a *systematic* and *requirement-oriented* engineering concept. Such an approach ensures that the obtained network configuration can be justified and that the quality of the solution obeys the specified bounds.

The application of *requirement-based* procedures claims to start the design process with an *analysis of the design constraints*. Additionally, it forces the specification of the design requirements and the definition of a functional model of the network. However, defining and parameterizing the requirements reveals to be an equal complex task as the network design itself. Therefore, automated tools are needed to support the design engineer. Especially the characterization of the economic design constraints, like demand estimation and revenue prediction, are not appropriately addressed so far in the planning process. Therefore, CUTE [7], the *Customer Traffic Estimation Tool*, was developed to support the design engineer during the specification and design task. CUTE enables a demand-based system engineering by introducing a new simple and efficient spatial traffic model. It is able to estimate the parameters of a spatial traffic model using publicly available geographical databases. In this way, CUTE enables and facilitates a truly requirement-oriented engineering concept.

The primary task of planning spatial-extended telecommunication networks is to locate and configure facilities, e.g., switching centers, base stations or other access points, within the service area and to interconnect them in an optimal way. Most traffic models applied so far in network planning are one-dimensional [6]. They describe only the temporal behavior of a traffic source seen at a fixed location. This characteristic makes them insufficient for engineering spatial systems. Their design requires an at least 3-dimensional traffic model. Beside the dimension of the temporal behavior, the model has to specify also the spatial variation of the traffic intensity within the service area. A simple as well as accurate method to describe the traffic within a service area is the application of discrete points, denoted as demand nodes. Every node represents the center of an area containing the same fixed amount of teletraffic. Each node can be regarded as a “customer” with a specific temporal behavior. The distribution of the demand nodes in the service area represents the spatial variation of demand.

Due to the application of the demand node concept, the integration of demand coverage requirements becomes straightforward. A typical design constraint of spatial telecommunication networks is to supply as many potential customers as possible. The use of the demand node concept in the design process permits, for example, the application of well-known facility locating methods. The facilities have to be located in such a way, that they supply a maximum of demand nodes, cf. [14].

3.1. Traffic estimation

The teletraffic originating from the service area of the network is estimated by CUTE using the geographical and demographical characteristics of the service area. This demand model relates factors like *land usage*, *population density*, *vehicular traffic*, and *income per capita* with the calling behavior of customers. The model applies statistical assumptions on the relationship of traffic and clutter type with the estimation of the demand. In the geographical traffic model, the teletraffic intensity $E_{\text{geo}}(x, y)$ is the aggregation of the traffic originating from these various factors

$$E_{\text{geo}}(x, y) = \sum_{\text{all factors } i} \eta_i \delta_i(x, y), \tag{4}$$

where η_i is the traffic generated by factor i in an arbitrary area element of unit size, measured in Erlang per area, and $\delta_i(x, y)$ is the assertion operator

$$\delta_i(x, y) = \begin{cases} 0, & \text{factor } i \text{ is not valid at } (x, y), \\ 1, & \text{factor } i \text{ is valid at } (x, y). \end{cases} \tag{5}$$

3.2. Traffic discretization and demand node

The core technique of the traffic characterization is the representation of the spatial distribution of the demand for teletraffic by discrete points, called demand nodes. Demand nodes are widely used in economics for solving facility location problems.

Definition 1. A demand node represents the center of an area that contains a quantum of demand from teletraffic viewpoint, accounted in a fixed number of call requests per time unit.

The notion of demand nodes introduces a discretization of the demand in both space and demand. In consequence, the demand nodes are dense in areas of high traffic intensity and sparse in areas of low traffic intensity. Together with the time-independent geographic traffic model, the demand node concept constitutes a static population model for the description of the mobile subscriber distribution.

An illustration for the demand node concept is given in the following figures. Figure 5 shows publicly available map data with land usage information for the area around the city of Würzburg, Germany. The depicted region has an extension of 15 km $\times$ 15 km. Figure 6 shows the traffic intensity distribution in this area, characterized by the traffic matrix: dark squares represent an expected high demand for mobile service, bright values correspond to a low teletraffic intensity. Figure 7 depicts

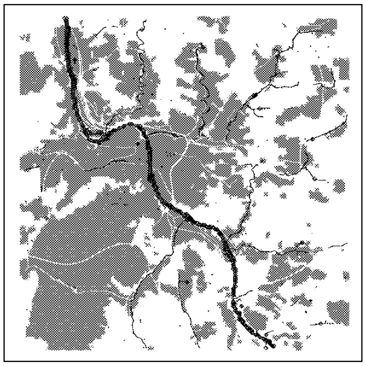

Figure 5. Land usage data (clutter data) of Würzburg data.

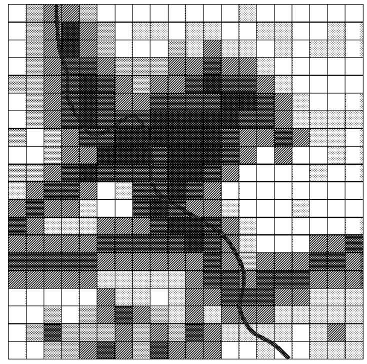

Figure 6. Traffic matrix of Würzburg data.

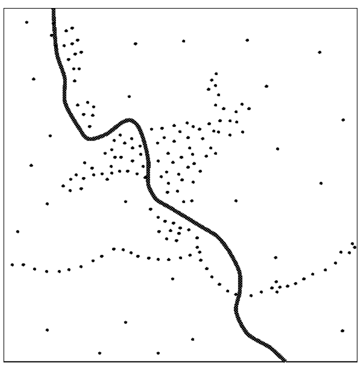

Figure 7. Distribution of demand nodes.

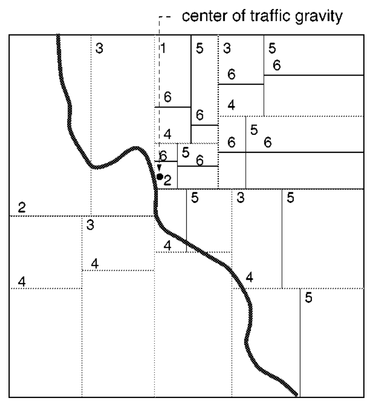

Figure 8. Partitional clustering method.

a simplified result of the demand discretization. The demand nodes are dense in the city center and on highways, whereas they are sparse in rural areas.

3.3. *Traffic characterization*

Based on the estimation method introduced in the previous section, the traffic characterization has to compute the spatial traffic intensity and its discrete demand node representation from real world data. In order to handle this type of data, the complete characterization process comprises four sequential steps:

1. *Traffic model definition.* Identification of traffic factors and determination of the traffic parameters in the geographical traffic model.

2. *Data preprocessing.* Preprocessing of the information in the geographical and demographical database.

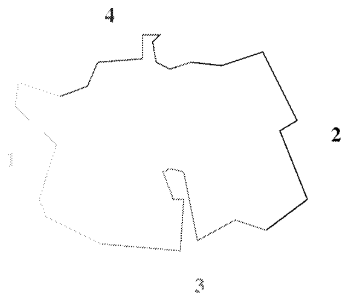

Figure 9. Unordered lines.

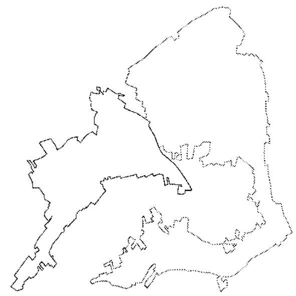

Figure 10. Adjacent open and closed polygons.

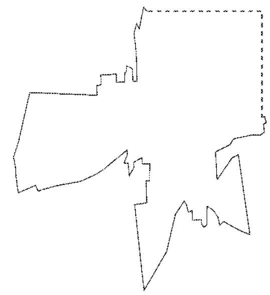

Figure 11. Closing lines.

3. *Traffic estimation.* Calculation of the spatial traffic intensity in the service region.

4. *Demand node generation.* Generation of the discrete demand node distribution by application of clustering methods.

The definition of the geographical traffic model in step 1 of the characterization procedure is based on the arguments given in section 3.2. A simple but accurate spatial geographic traffic model is the basis for system optimization in the subsequent network design steps.

3.3.1. Data preprocessing

The data preprocessing in step 2 is required since the data in geographical information systems is usually not collected with respect to mobile network planning. The main objective is to maintain map information and use a vector format for storing their drawing objects.

To determine the clutter type of a certain location, one has to identify the land type of the area surrounding this point. This requires the detection of the closed polygon describing the shape of this area. Since maps are mostly printed on paper, the order of drawing the lines of a closed shape does not matter, see figure 9. To identify closed polygons, one has to check if every ending point of a line is a starting point of another one. If a closed polygon has been detected, the open lines are removed from the original base and replaced by its closed representation. Additionally, due to the nature of the data, two adjacent area objects can be stored by a closed and an open polygon, see figure 10. It also can happen that some data is missing, see figure 11. In this case, line closing algorithms have to applied. After the preprocessing step only closed area objects remain in the database and the traffic characterization can proceed with the demand estimation.

3.3.2. Demand estimation

Step 3 of the traffic characterization process uses the geographical traffic model defined in step 1 for the estimation of the teletraffic demand per unit area element. The computed traffic values are stored in the *traffic matrix*. To obtain the traffic value on a certain unit area element, the procedure first determines the traffic factors valid for this element and then computes the matrix entry by applying equation (4).

3.3.3. Demand node generation

The generation of the demand nodes in step 4 of the characterization process is performed by a *clustering method*. Clustering algorithms are distinguished into two classes:

1. *Partitional clustering* methods, which try to construct taxonomies between the properties of the data points, and

2. *Hierarchical clustering* methods which derive the cluster centers by the agglomeration of input values.

The algorithm proposed in this article for the demand generation is a recursive partitional clustering method. It is based on the idea to divide the service area until the teletraffic of every tessellation piece is below a threshold θ. Thus, the algorithm constructs a sequence of bisections of the service region. The demand node location is the center of gravity of the traffic weight of the tessellation pieces.

The demand node generation algorithm is shown in algorithm 2. The function `left_area()` divides the area into two rectangles with the same teletraffic and returns the left part of the bisection. The function `right_area()` returns the right piece. In every recursion step, the orientation of the partitioning line is rotated by 90°. The recursion stops, if every rectangle represents a traffic amount less than the minimal

Algorithm 2. Generate Demand Nodes

variables:

`dnode_set`	global variable for the set of generated demand nodes
`orient`	orientation of the partitioning line
θ	traffic quantization value

algorithm:

```
proc gen_dnodes(area, θ, orient = 0)
     begin
          if (traffic(area) < θ)
          then
               dnode_set ← center_traffic(area);
               return;
          else
               orient ← (orient+90°) mod 180°;
               a_l = left_area(area, orient);
               a_r = right_area(area, orient);
               gen_dnodes(a_l, θ, orient);
               gen_dnodes(a_r, θ, orient);
          fi
     end.
```

Figure 12. Algorithm for demand node generation.

quantization value θ. The function `traffic()` evaluates the amount of expected teletraffic demand in the area.

An example for the bisection sequence of the algorithm is shown in figure 8. The numbers next to the partitioning lines indicate the recursion depth. To make the example more vivid, not every partition line is depicted in the example. The upper left quadrant of figure 8 shows only the lines until the recursion depth 3, the lower left part the lines until the depth 4, the lower right quarter the lines until depth 5 and the upper right quadrant of the region the lines until depth 6.

The partitional clustering algorithm of algorithm 2 is a fast but simple clustering method. However, its accuracy depends strongly on the quantization value θ, which gives only an upper bound for the traffic represented by a single demand node. Moreover, since the algorithm constructs a sequence of right-angled bisections, the shape of the tessellation pieces is always rectangular. To overcome these drawbacks, we investigated also hierarchical agglomerative clustering algorithms, cf. [18]. These methods are able to obtain tessellation pieces of arbitrary shape and of a predefined traffic value.

4. CDMA network planning issues

The recent introduction of wireless Code Division Multiple Access (CDMA) networks has led to several new issues in system capacity design that will be addressed in this section. Beside the success of the North American networks based on the IS-95 standard by Qualcomm Inc. (cdmaOne), CDMA has become a global issue especially after the efforts of the ETSI in agreeing on the standard of the air interface of the third generation system UMTS to be a wideband CDMA system. However, since most of the newly rolled-out networks have often not yet reached their full operation conditions, the effects of varying traffic load on coverage and capacity still need to investigated. In traditional F/TDMA systems coverage is purely determined by RF transmission aspects and the maximum capacity of the cell is only limited by the number of radio terminals at the base transceiver station (BTS). Since the communication channels are separated by different time and frequency slots, interference among users within the same cell can be neglected. In CDMA, however, all users access the same frequency band simultaneously. Each communication channel is separated by modulating the data signal with a noise-like carrier, which is unique for the link, and spreading the modulated signal over a large frequency bandwidth. Since the signal appears like noise over the channel, the signals from all other users constitute a certain level of interference. This leads to a new definition of capacity, the *soft-capacity* [20]. According to this concept it is permitted to accept more users to the cell at the price of a slight loss in quality in terms of mean *signal-to-interference ratio* (SIR). Due to this soft-capacity nature of CDMA networks, the coverage of a cell depends on several factors:

(1) transmission characteristics of the terrain,

(2) dynamics of the power control procedure [9],

(3) desired quality of service in terms of sustainable interference level,

(4) spatial customer distribution and corresponding time-dependent customer traffic intensity.

The fact that capacity in CDMA is influenced by the number of users in the cell also lets the cell coverage area be considered as elastic. This indicates that both the customer population and its spatial distribution has to be taken into account in the context of CDMA network planning, especially in the design of connection admission control (CAC) and overload control algorithms. Accepting a new call to an overloaded cell would cause that those users at the fringe of the cell would face a deteriorating service.

4.1. Two-dimensional cluster process and call outage

We consider a cell in a CDMA network with a BTS supporting a number of calls (figure 13). At the moment of observation there are k calls to be supported and power-controlled in the cell. We observe a user i in conversation phase. This is the period when a user transmits an activity burst during his call. This distinction of activity/inactivity is necessary since the vocoders make use of voice activity during coding in order to further decrease the total system interference.

We use as performance metric of the network an expression for *outage probability*. This is the probability that the signal-to-interference ratio does not reach a desired minimal threshold level. To estimate coverage and outage probability in a network planning context, we consider in the following the customer population on a 2-dimensional surface to constitute a spatial homogeneous Poisson process. Thus, the distribution of the random variable K_A of calls on a surface area A is Poisson distributed as

$$P(K_A = k) = \frac{(\lambda A)^k}{k!} \mathrm{e}^{-\lambda A}, \tag{6}$$

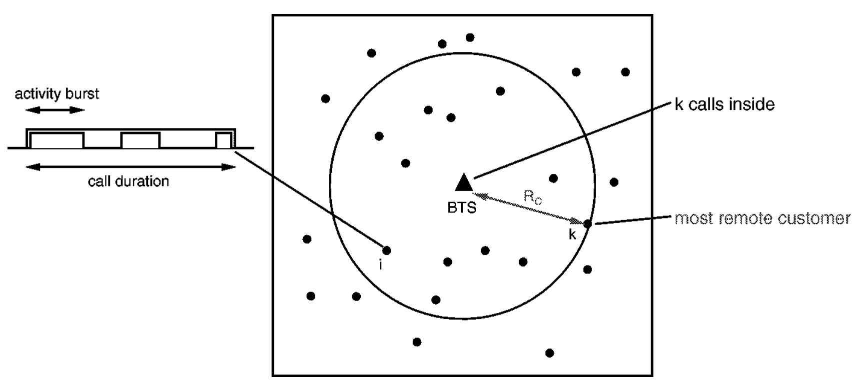

Figure 13. CDMA cell with k supported users.

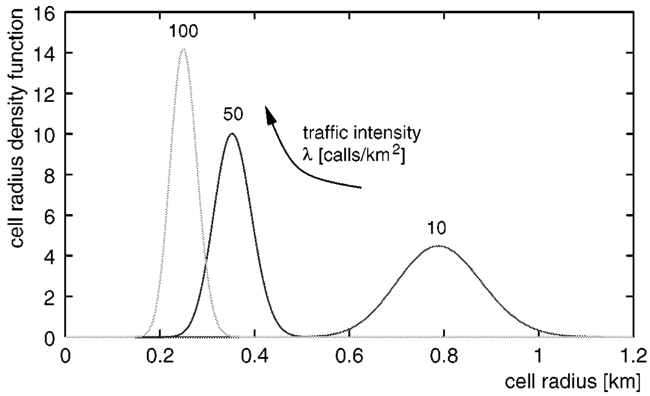

Figure 14. Density function of the cell radius for different spatial traffic intensities.

where λ (in calls per km^2) denotes the spatial traffic intensity. The distribution of K_A is valid at any arbitrary observation instant.

Based on this Poisson process assumption we now consider a cell modeled by a circle with radius R_{C}. One active call is assumed to be on the radius and $k-1$ connections are inside the circle (figure 13). The corresponding coverage area is $A = \pi R_{\mathrm{C}}^2$. Thus, the random variable A stands for the surface of the smallest circle containing k points of the 2-dimensional Poisson process. Due to the property of the spatial Poisson process, the size of the coverage area A is distributed according to an Erlang-distribution of order k with probability density function

$$a(y) = \frac{\lambda(\lambda y)^{k-1}}{(k-1)!}\mathrm{e}^{-\lambda y}. \tag{7}$$

For our computations, the cell radius is more useful than the coverage area, as this translates directly to the distance between most remote user and base station

$$r_{\mathrm{C}}(x) = \frac{2\lambda\pi x(\lambda\pi x^2)^{k-1}}{(k-1)!}\mathrm{e}^{-\lambda\pi x^2}. \tag{8}$$

We can now calculate the probability to have a cell radius of x for a cell currently supporting k calls assuming an intensity of λ. It can be shown that to support fewer calls, the mean cell radius is, in general, smaller than for larger values of k, for a fixed traffic intensity of λ.

In figure 14 the curve for $r_{\mathrm{C}}(x)$ is plotted with a fixed value of $k = 20$ and varying traffic intensities λ. It indicates that for areas with high values of λ, e.g., urban or dense urban regions, the cell radius is more clearly defined than for areas with lower intensity.

4.1.1. Cell coverage in a CDMA network

Considering the 2-dimensional user traffic process, the coverage area of a CDMA cell will be estimated, where the outage probability given in [19] will be taken as the criterion to define the boundary of a cell. The expression given there for outage probability is

$$P_{\text{out}}(x,k) = Q\left(\frac{S_{\max} - PL(x) - m_S(k)}{\sqrt{\sigma_S^2(k) + \sigma_Z^2}}\right), \tag{9}$$

where $S_{\max}$ is the maximum MS transmit power, $PL(x)$ is the propagation loss as function of the distance x. The mean and standard deviation of the received MS power at the BTS as function of the traffic load are given as $m_S(k)$ and $\sigma_S(k)$, and σ_Z represents the standard deviation of the log-normal shadowing.

With the Poisson process assumption we now have a mechanism to describe the probability to have k calls in the cell with radius x and the probability of the cell with k calls to have a radius of x. With both probabilities we can get expressions for the overall outage probability, just depending on one of the parameters x or k and the traffic intensity λ. For the estimation of λ, we can use a method like described in section 3. Therefore, it is enough to know the environment of the cell, such as urban or rural and map this value to a certain value of λ.

First we look at a cell with radius $R_{\mathrm{C}} = x$. The probability to have k connections being active in the cell with radius x is Poisson distributed and the overall unconditioned outage probability for this cell can then be derived as

$$P_{\text{out}}(x) = \sum_{k=1}^{\infty} P_{\text{out}}(x,k) P(K_A = k). \tag{10}$$

We now focus on the question, how large the coverage area of a CDMA cell is if we want to cover a given number of k active calls. From network design viewpoint the coverage corresponds to a chosen outage probability, which can be derived by combining equations (8) and (9),

$$P_{\text{out}}(k) = \int_0^{\infty} P_{\text{out}}(x,k) r_{\mathrm{C}}(x)\, \mathrm{d}x. \tag{11}$$

Here, it is no longer necessary to know the distances of the individual users, as these are being implicitly represented by the Poisson process.

The interactions between customer and capacity dynamics lead to new definitions of the terms coverage and capacity of a CDMA cell. In particular, consider figure 15. It is clear that the rate of change of $P_{\text{out}}(x)$ as a function of distance is small until it reaches a point where it extends exponentially. The curve approaches a step function for a limit of $\lambda \to \infty$. Thus, for a CDMA cell the capacity and coverage are both provisionable quantities and will be dominated by stability issues more than actual resource constraints. In general, given a spatial traffic intensity λ and P_{out}, the capacity and coverage of the cell can both be determined by stability arguments.

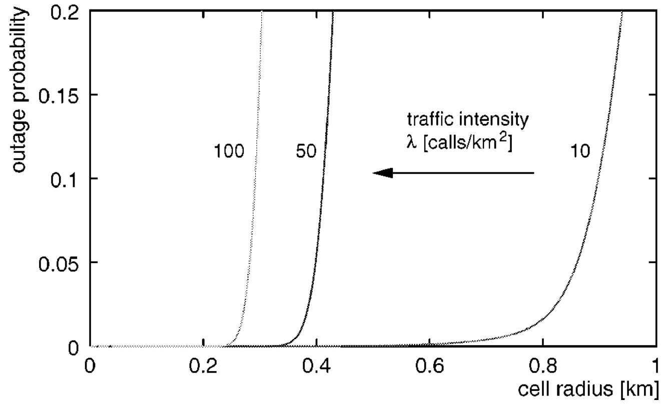

Figure 15. Impact of customer-BTS distance on outage probability.

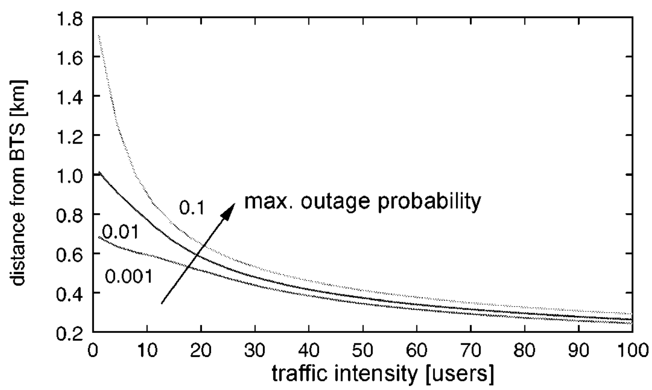

Figure 16. CDMA traffic based network planning.

4.2. CDMA network planning with 2-dimensional customer traffic

With the findings in section 4.1, we can now perform a traffic-based CDMA network planning for a given area. The great advantage of CDMA network planning in contrary to the design of conventional F/TDMA systems is that since there is a universal frequency reuse, no further frequency assignment and planning is necessary. This permits an easy and fast estimation of the inter-BTS distances when performing the first planning of a new area.

Let us consider figure 16. In this curve we can obtain the maximum distance that a MS can have from the BTS in order to maintain a required maximum outage probability and when the traffic intensity in the region is known. This curve also shows us that when the traffic intensity increases to a very high level, the maximum distance is rather independent of the desired outage requirement. When setting up the BTS according to the distances from the curves in figure 16, we also achieve an additional gain at the cell boundaries, the area where it is most likely to encounter an outage, through the soft-handoff ability of the system [2].

5. Conclusion and outlook

In this paper we presented an overview of different teletraffic issues in mobile communication network planning. It was shown that due to the 2-dimensional clustered nature of the traffic distribution, care has to be taken to perform a demand-based network planning. If the clustered nature of the teletraffic is neglected the subjective QoS is worse when dealing with clustered traffic.

We have presented an algorithm to obtain clustered 2-dimensional traffic distributions, which makes use of the obvious relationship between population and demographic data and traffic demand. This discrete algorithm permits the use of methods from facility location theory to position the fixed network components such as transmitters and switches. The proposed framework of the demand node concept enables the matching of practice and theory in mobile network planning, cf. [5]. The methods suggested in this chapter have been submitted to the ITU-T's focus group on traffic engineering for personal communications (FG-TEPC). FG-TEPC is considering how to harmonize the Demand Node framework with the procedures described in ITU-T E.750 series draft recommendations on terminal mobility.

We have also shown that for analyzing CDMA networks it is especially necessary to take the spatial customer traffic distribution into account in the planning and network design process. Since traffic intensities will vary over time it is important to also observe the time-varying nature in the traffic model. The model presented here is only considered as a first approach of a stationary user distribution of the busy hour of the cell. The homogeneous case can easy be extended to a more general case where the traffic in the observed area is nonhomogeneous. To include time dynamics in the model, like temporal migration of hot-spot regions, the use of a time-varying spatial process, e.g., [1], can be considered. This can be useful when observing the impacts of the time dynamics of the power control loops on the capacity of the CDMA system [9]. The growing importance of CDMA networks and the capacity problems that are appearing in the CDMAOne system show that an analytical computation of the teletraffic capacity is necessary. New technologies based on CDMA like the standardized UMTS also illustrate the need for an extension of the analytical techniques.

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