A Network Planning Tool for Location Area Forming in Next Generation Mobile Access

V. Simon, T. Van Leeuwen, G. Péterfalvi, S. Imre, *Member, IEEE*, and I. Moerman, *Member, IEEE*

***Abstract*— In the next generation mobile communication networks the delivery of multimedia traffic will become an increasingly important and difficult issue as cell sizes shrink to accommodate continuously larger demand for high capacity. These networks should keep handover delay limited to reduce the impact on the perceived quality of time sensitive real time multimedia applications. Careful network planning is therefore indispensable to be able to guarantee the necessary QoS, especially for vehicular users. In this paper we introduce a network planning tool for domain forming, which takes into account the mobility dynamics of the subscribers, such that handover signaling overhead is minimized. This work has been performed in the framework of the IST NEWCOM project.**

***Index Terms*—domain forming, handover signaling, network planning, vehicular users**

I. Introduction

THE increasing trend towards smaller cell sizes, makes efficient mobility management strategies indispensable for radio resource management and network planning in next generation cellular networks. The common practice in designing radio resource management or network planning techniques is to apply static mobility models which do not take the dynamics of user mobility into account. However, this does not reflect the realistic behavior of mobile clients in vehicles, because their handover rate, location area change rate, dwell time, etc are dependent on their interaction. Therefore, the network signaling load will be very different depending on the location and the user density dynamics. For a given environment, the cellular network needs to be designed with these user mobility characteristics in mind, such that it is able to guarantee the necessary quality of service to its customers.

The delay and the delay variation are one of the most important QoS parameters in next generation micro-cell IP based mobile networks. The performance of such networks can be threatened by high handover frequencies and an increasing handover signaling overhead [1]. This affects the delay variation experienced by the users, which is critical in the case of time sensitive real time media applications. The handover signaling overhead is due to the management of the mobile users' location information: when they change location areas, their home agents need to be updated.

A mobility management solution, such as location area domain forming is capable of reducing this signaling overhead. The location area structure dictates that several cells are joined into one administrative unit, a so-called location area (LA). The cell border crossings inside this domain will remain hidden for the upper hierarchical levels, thus reducing signaling overhead. Only when an LA border is crossed, the location is updated; not on each cell handover. The question then arises: what size the LA should be? Namely if more and more cells are joined into one LA, then the number of LA handovers will be smaller and the number of location update messages sent to the upper levels will decrease as well. But in this case, an incoming call will cause lots of paging messages in order to locate the mobile user inside this LA. This will increase the load at the base stations. If we decrease the number of cells per LA, then the links will be less loaded with paging messages, but the number of LA change updates will increase, especially in a vehicular environment. We must therefore search for the optimal compromise between this two conflicting requirements [2]. The determination of the optimal number of cells in each location area (LA) has been proven to be an NP-hard problem.

The LA management is classified according to its use of time, distance, movement profile information in its paging and location update procedures. The location update can be performed due to the time elapsed since the last registration process [3] or the number of cell boundary crossings measured since the previous update [4]. Wong et al. recommend a distance-based scheme, where the location update will be performed, when a mobile user moves a threshold number of cells away from the cell where the last registration process was carried out [5]. The hybrid of distance-based and zone-based is studied by Casares-Giner et al. [6]. Bar Noy el al. [7] have compared time-, distance-, and movement based schemes in terms of location management cost, and they have shown that the distance-based one performs best. However its implementation is hard because the distance of the mobile terminal has to be computed dynamically as it moves from cell to cell.

In this paper; we propose a zone-based LA solution to

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decrease the amount of administrative messages and thus increase the performance of the mobile network. Within the IST NEWCOM project, we have therefore developed a common network planning tool for location area forming in next generation mobile access networks, focused on vehicular environments. The rest of the paper discusses the architecture of our planning tool, including its two most important components: the LA forming algorithms and the mobility and call arrival simulator.

II. NEWCOM PLANNING TOOL ARCHITECTURE

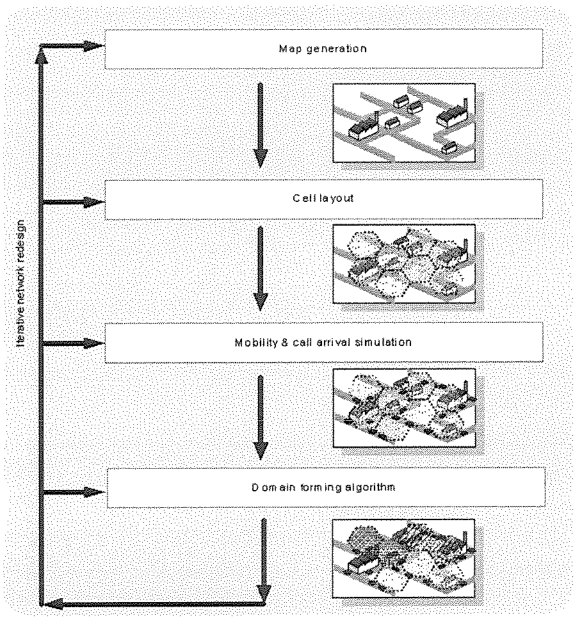

Fig. 1. Architecture of the NEWCOM planning tool.

Fig. 1 shows the functional blocks of our network planning tool. First, a street map of the corresponding environment is drawn using the graphical user interface. In the second phase, the location of the antenna base stations is determined and placed on the map. The following paragraphs describe in detail the rest of our planning tool architecture.

A. Mobility and call arrival simulator

In order to take user mobility dynamics into account for the network planning, a good description of the mobility characteristics and the interaction of different types of users is needed. We have developed an extendable JAVA mobility simulator that can simulate the behavior of mobile users on a given street plan in a realistic way, using an extended version of the Nagel-Schreckenberg model [8]. Current mobility simulators give the users the unrealistic freedom to move every where they want. However, the environment physically limits this freedom: users (e.g. cars, trains, ...) can only move inside certain areas and react to the changing environment and the behaviour of other vehicles. For example, if a car approaches a traffic jam at a junction, it has to slow down and eventually stop. Every other car on the same road is affected by this: they have to slow down or stop as well. In this way, the simulator can, to a certain extent, mimic real vehicular movements in a (semi-) urban environment. Our mobility simulator applies the Dijkstra algorithm for every vehicle to determine the path to their destination. The cost of each road is determined by its length, its speed limit and the number of vehicles on it. In this way, the main roads with higher speed limit will be preferred. Additionally, in case of a traffic jam, the vehicles will try to avoid this congested road and choose an alternative road to get to their destination. At the beginning of the simulation, the vehicles are placed on the map and will be assigned a given call arrival intensity, a destination and a maximum speed. After the simulation, cell change and call arrival intensity matrices will be produced and fed to the next functional block: the domain forming algorithm.

III. COST STRUCTURE

On the arrival of an incoming call, the mobile switching center sends a paging message to every base station under its control, in order to locate the called mobile terminal (MT). So each cell in the given LA will carry all the paging traffic associated with the called MTs within that LA. We define the cost of the paging message traffic, in terms of bandwidth, for a given LA partitioning, generated by the incoming calls in a given interval:

$$C_p = \sum_{l=1}^{M}\sum_{i=1}^{K} N \cdot \lambda_i \cdot B_p = \sum_{l=1}^{M} N \cdot B_p \cdot \sum_{i=1}^{K} \lambda_i \quad (1)$$

where

N is the number of cells in the given l^{th} LA

λ_i is the incoming call rate to the given i^{th} MT

B_p is the paging cost

K is the number of MTs in the l^{th} LA

M is the number of LAs in our system.

Mobile users crossing the LA boundaries will have to update their location at their MSCs. Therefore , we define a location update cost function for our network by:

$$C_{lu} = \sum_{l=1}^{M} B_{lu} \cdot \sum_{j=1}^{B} q_j \quad (2)$$

where

B_{lu} is the cost required for transmitting a location update message

q_j is the intensity of cell boundary crossings on the j^{th} boundary

B is the number of the exterior cell border-lines

M is the number of LAs in our system.

Our final goal is to maximize the intra-domain traffic, such that we can decrease the number of the LA handovers and by this the total amount of signaling. We can reduce the handover number by joining those cells that are on the dominant moving directions.

IV. THE LOCATION AREA FORMING ALGORITHM

We model our network with the $G(V,E)$ graph, where the cells are the graph nodes $v \in V$, and the cell border crossing directions are represented with the edges $e \in E$ of the graph. A moving direction probability matrix can be deduced for every cell from the output of the mobility simulator, where the weight of the edges is consistent with the cell border crossing probabilities. We divide graph $G(V,E)$ into maximum weight spanning tree subgraphs $G_i(V,E)$, which define the cell groups that compose the LAs.

On each step we choose from edges the one, which has the biggest weight and include it into a new set Ui, except when this edge connects a node, which was already in an existing set U_k In this case we check the inequality

$$\frac{c_m}{\frac{1}{n} \cdot \sum_{i=1}^{n} c_i} > K \qquad (3)$$

is satisfied, where c_m is the weight of the examined edge, and c_i are the weights of edges in the U_k set. K is the lower bound, given by us. If the inequality is satisfied, the edge can be included into U_k. If the inequality is not satisfied, this edge can not be included into this set, namely the cell which is represented with this node, can not be joint into this LA. Another upper bound can be used, we can give the maximum number of cells in one LA. We run this algorithm until we get the U_i partition of nodes V, so this partition will give us the cluster-groupings of the cells, namely the D_i location areas.

V. THE REGROUPING ALGORITHM

The partition of cells is an NP-hard problem. Therefore we propose a heuristic regrouping algorithm to obtain the optimal location area design. This algorithm uses

the border crossing intensity $Y_{i1} = q_{iF}$

the total expectation value of the incoming call distribution for all users of a cell i in a given interval

$$Y_{i2} = \sum_{j=1}^{N} \lambda_j$$

as outputted by the mobility simulator. We then define a two dimensional probability variable $Y_i = (Y_1, Y_2)$ for cell i.

The location area forming algorithm gives us a partition of cells $\{D_1, D_2, \ldots D_M\}$ in M location areas.

Furthermore, we define the centre of the location area D_i by

$$\overline{D_i} = \frac{1}{|D_i|} \sum_{Y_l \in D_i} Y_l \qquad (4)$$

The distance of the Y_j cell from the D_i location area is

$$d(Y_j, D_i) = d(Y_j, \overline{D_i}) = \left(\sum_{l=1}^{2} (Y_{jl} - \overline{D_{il}})^2 \right)^{1/2} \qquad (5)$$

A very important parameter in our regrouping algorithm will be the error function of our location area system

$$W(D_1, \ldots D_M) = \sum_{i=1}^{M} \sum_{Y_j \in D_i} d^2(Y_j, D_i) \qquad (6)$$

Our goal is to minimize the error function by transposing the cells into adjacent location areas, and by this we can reduce the distances among them, what will result in a significant reduction of location update and paging costs.

Steps:

1. The calculation of the initial area centres and the initial error function $(\overline{D_i}, W(D))$

2. For the first cell (Y_1) and the adjacent location areas (D_i), given by our location area forming algorithm, we calculate:

$$\Delta(D_i, Y_1) = \frac{|D_i| \cdot d^2(Y_1, D_i)}{|D_i| + 1} - \frac{|D(Y_1)| \cdot d^2(Y_1, D(Y_1))}{|D(Y_1)| - 1} \qquad (7)$$

where $D(Y_i)$ is the location area, which contains the Y_i cell. We can prove that if we re-group the Y_1 cell from the $D(Y_1)$ location area to the D_i area, the error function of our location area system will change by exactly $\Delta(D_i, Y_1)$.

So if

$$\min_{\substack{1<i<M' \\ D_i \neq D(Y_1)}} \Delta(D_i, Y_1) = \Delta(D_k, Y_1) < 0 \qquad (8)$$

where M' is the number of the location areas which are adjacent with cell Y_1, then we transpose the cell Y_1 from location area $D(Y_1)$ to D_k.

Calculate the new location area centres and add the $\Delta(D_k, Y_1)$ to the former error function value.

3. Iterate the 2. step for every Y_i.

4. If there are no more cells to transpose, we can stop, otherwise repeat step 2.

This regrouping algorithm will give us the final LA partition, which will minimize the inter LA movement, and by this the signaling load.

VI. RESULTS

We compared the performance of a manual LA partition and the LA forming algorithm, by using two typical mobility environments as reference (Fig. 2).

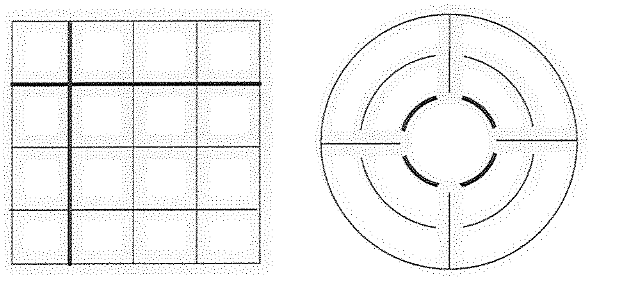

Fig. 1 The Manhattan city model and the European city model with main roads in bold

In the Manhattan city model, two roads (bold) have a higher speed limit, which makes them more attractive for drivers. Each junction has traffic lights in order to avoid dead locks. In the European city model, the inner ring (bold) is more likely to be chosen as destination. This represents the morning rush hour situation where people converge to work in the city centre.

Furthermore, we define four classes of traffic conditions ranging from low to high average vehicle density and from low to high call arrival rate per vehicle (Poisson distribution, calls per hour) (Tab. 1). Note that during the simulation, the local vehicle density will be much higher, especially in the area around junctions. We also deployed a number of cells with diameter of 0.78 km on the city map, such that coverage was total.

TABLE 1 MOBILITY SIMULATION PARAMETERS

	Vehicle density		Call arrival rate (λ)	
	Manh.	*Euro.*	*Manh.*	*Euro.*
Class I	0.5%	0.4%	1	1
Class II	0.5%	0.4%	8	8
Class III	3.3%	2.8%	1	1
Class IV	3.3%	2.8%	8	8

A. Employing only the LA forming algorithm

Once the LA partitions have been determined, we computed the location update cost (in total number of handovers between the LAs in the simulation period), and we computed the same cost for a manually designed LA partition, where we predefine the number of cells in one LA. In this case we did not take into account the vehicle mobility dynamics. The value for the lower bound K was set to 0.5.

For the European city model the results of the simulation are given in Fig. 3, where the call arrival and MT density axis represent the four classes, combining the two means of call arrival rate and two different vehicle densities. Obviously, the more vehicles in the environment, the higher the total LA update cost for the network. Fig. 1 shows that the LA forming algorithm can significantly reduce the location update cost, even in high call arrival rate.

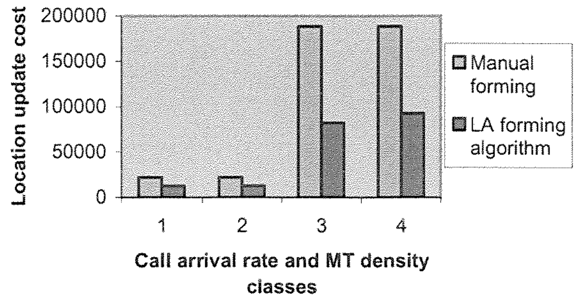

Fig. 3. The location update cost for the European city model

In Fig. 4 the results for the Manhattan city model are depicted. Again, the location update cost is remarkably reduced, but not so significantly as in the previous model. Due to the Manhattan grid pattern, the vehicles have much more alternative routes to choose from. This increases the total number of LA changes and the LA update cost.

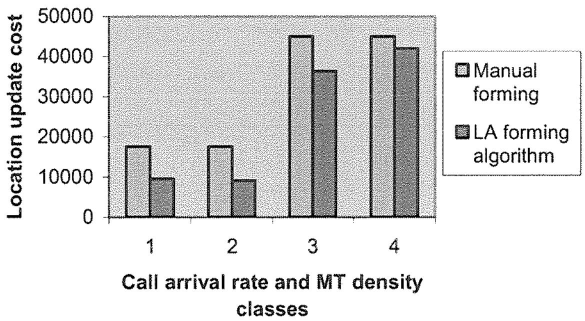

Fig. 4. The location update cost for the Manhattan city model

B. Employing both algorithms

We have examined what will happen if we employ our regrouping algorithm on the initial partitioning obtained by the LA forming algorithm. We measured the total cost, the sum of the location update and paging cost, for the four classes.

Fig. 5 shows the total cost for European city model. The LA forming algorithm is not so effective anymore (because it is developed for reducing the location update cost, not the total cost), but the regrouping algorithm is still outperforming the other two partitioning methods significantly, in some cases more than 50%.

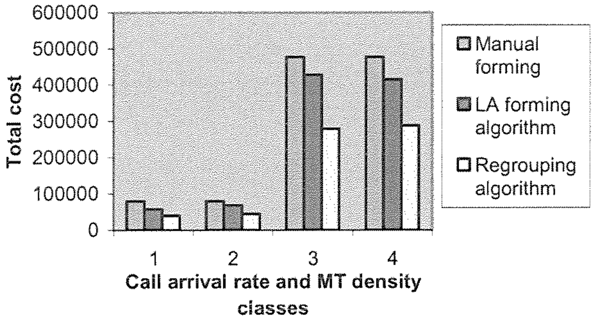

Fig. 5. The total cost for the European city model

In the Fig. 6 the Manhattan city model total cost is displayed. Again, the regrouping algorithm proves to be very effective in reducing the signaling cost.

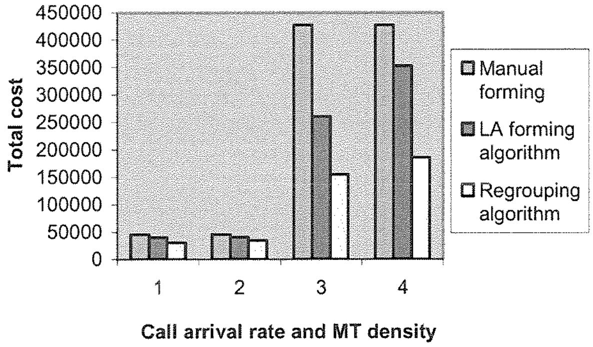

Fig 6. The total cost for the Manhattan city model

Depending on our objective we can deploy either the LA forming algorithm or the regrouping algorithm. If we want to decrease the location update cost, the LA forming algorithm is the solution, however if we want to decrease the total signalling cost, we need to employ the regrouping algorithm.

VII. Conclusions

In next generation micro cellular networks, quality of service, in terms of delay and delay variation of time critical multimedia applications, is influenced by handover signaling. In this paper we have presented a network planning tool which determines the optimal partitioning of cells into location areas, such that signaling is minimized. The input to the algorithms was obtained by a mobility simulator that produces network information (base station transition matrix, incoming call distribution to every cell) for realistic vehicle mobility behavior. While traditional network planning tools assume a static user demand, our network planning tool takes the mobility dynamics of the users into account and is therefore able to plan a more efficient mobile access network for a given environment. An important benefit of optimized LA planning is preventing needless radio resource usage, but the most important is that we can support global QoS parameters, like signalling delay and delay variation.

It can be achieved by reducing the signalling cost, which means that the inter LA movement must be minimized. Most of the references [9], [10] related to the location area design are focused on how to determine the optimal number of cells for an LA. In this paper we presented an algorithm which can give us the partition of cells into LAs. We also proposed a cell regrouping algorithm, which uses the LA partitions obtained by our algorithm, like an initial step.

The simulation results show that the LA forming technique reduces the location update cost by 40-60 percents, while the regrouping algorithm decreases the total cost of our system by 30-40%, sometimes even more than 50%, in comparison with manual LA forming. Our network planning tool is therefore able to significantly reduce the signaling traffic overhead, which causes delay and delay variation, and thus improves the quality of service for the subscribers of the system.

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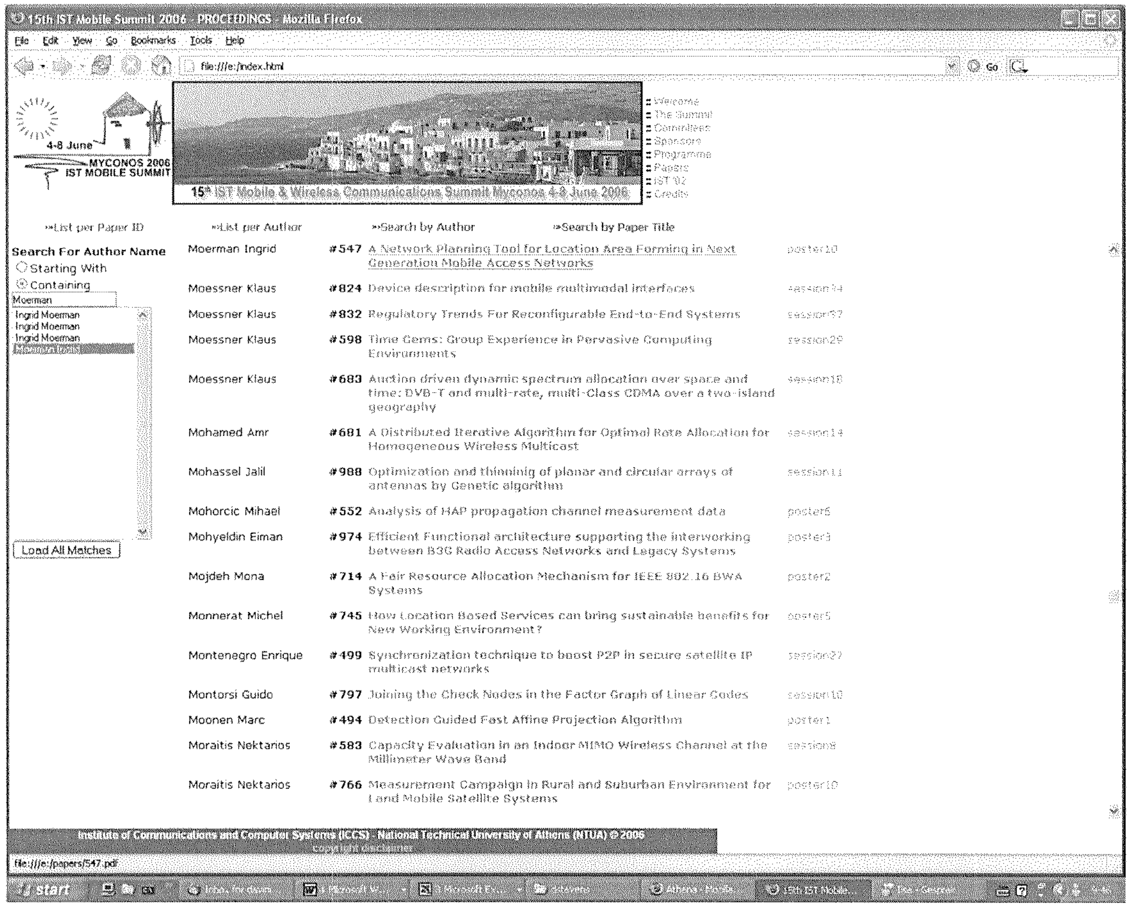
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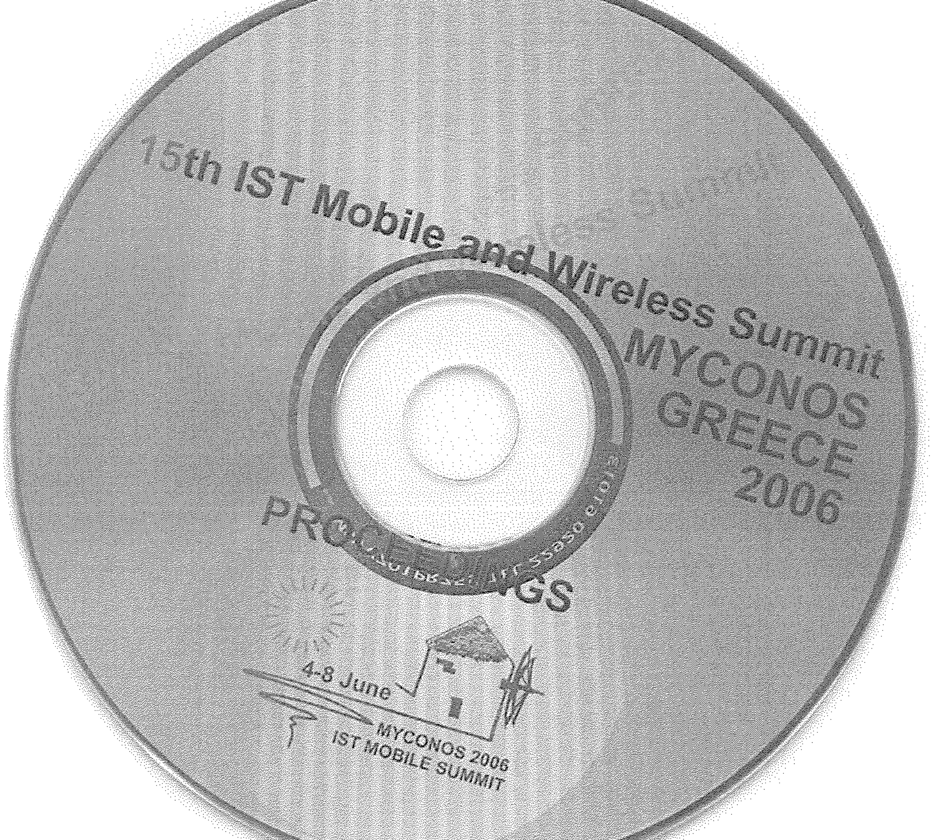
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