INTERACTION OF POWER CONTROL AND LINK ADAPTATION FOR CAPACITY ENHANCEMENT AND QoS ASSISTANCE

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Abstract
Within this paper we present a new strategy for applying Power Control in combination with Link Adaptation in order to satisfy required Quality of Service (QoS) parameters and to possibly enhance the overall capacity of HIPERLAN/2 micro cellular systems. The efficiency of our algorithm is then investigated and evaluated by means of simulations.

Keywords Link Adaptation, Power Control, Quality of Service, HIPERLAN/2

I. INTRODUCTION

Modern radio access systems like HIPERLAN/2 (H/2) [1][2][3] offer different combinations of coding and modulation schemes, so called PHY-Modes, to be applied. Basically, higher PHY-Modes enable higher data rates but since they are less robust towards interference on the link a respective high carrier to interference (C/I) ratio is needed. Otherwise an increasing packet error rate (PER) results in the need of many packet retransmissions, which means higher delay and lower throughput. In order to achieve a suitable high C/I, the transmitting device (Mobile Terminal, MT, and/or Access Point/Central Controller, AP/CC) could increase its transmission power. However, this results in a deterioration of the current interference situation. Especially, hidden nodes might suffer from this approach.

Thus, the focus of this paper is to investigate the interaction of Power Control, Link Adaptation and interference within a certain scenario and to work out a strategy to combine these mechanisms. The scenario is under control of a CC or AP, where links exist between each terminal (MT) and the AP/CC (In the following we only use the notation AP). If a certain amount of data is to be transmitted, we basically will have to transmit the data with high power for a short time (high PHY-Mode) or with lower power for a longer time (low PHY-Mode). However, if the same PER shall be reached for both transmission options, the higher PHY-Mode needs to be used with increased transmission power, which might result in a worse overall interference situation.

II LINK ADAPTATION AND POWER CONTROL

In order to adapt the transmission to the channel quality H/2 offers Link Adaptation (LA) and Power Control (PC). On the physical layer, there are 7 different combinations of modulation and coding schemes possible, offering a data rate between 6 Mbit/s and 54 Mbit/s (cf. Figure 1: PER versus C/I for different PHY-Modes, following the BRAIN D-model [4][5]).

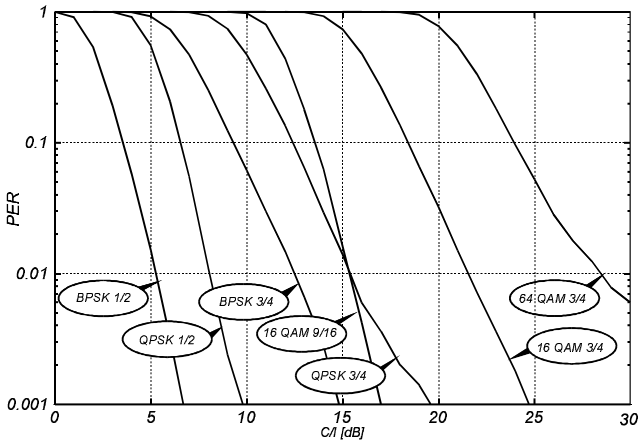

Figure 1: PER versus C/I for different PHY-Modes

Based on the transmission quality (PER,C/I) the AP selects a suitable PHY-Mode according to the requirements of the connections. The selection of an appropriate PHY-Mode is based on the status (PER,C/I) of received packets that is used to predict the future channel conditions [8]. The switching points, where to change from one PHY-Mode to another, can be used to optimise the LA on throughput or PER. A lower PER, e.g., is required for time critical services to avoid additional delay resulting from retransmissions. For data services (e.g. FTP) the LA is optimised on throughput. The PHY-Mode to be used for a connection is announced within a control channel (the Frame Channel , FCH) and can be changed from frame to frame. The usability of a certain PHY-Mode is also influenced by the transmission power of the sender. A higher transmission power increases the C/I and enables the AP to use higher PHY-Modes resulting in a higher data rate.

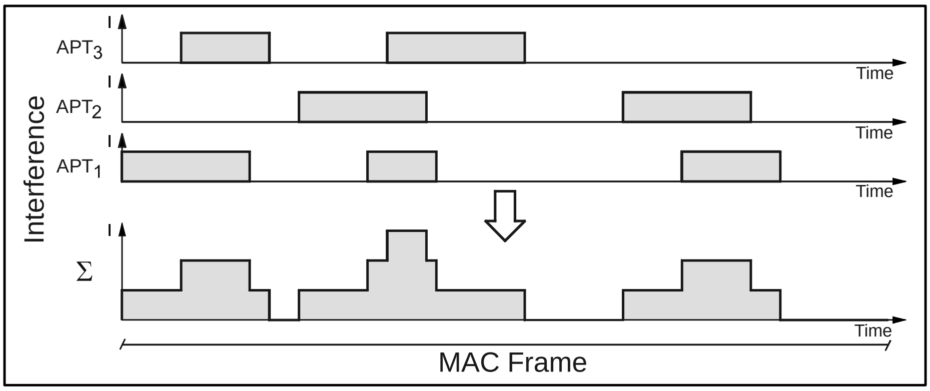

Figure 2: LA/PC approach with highest transmission power and highest PHY-Mode

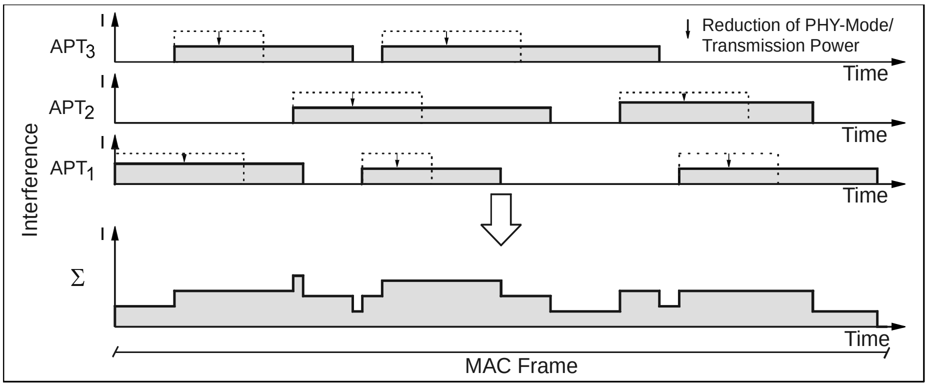

Figure 3:LA/PC approach with reduction of PHY-Mode and transmission power

On the other side a higher transmission power increases the overall interference.

Thus, it is important to develop a strategy that considers the aspects of LA and PC to achieve an optimal solution. We thereby need to consider that scenarios usually cannot be seen as stand-alone islands. Therefore, the influence of co-channel interference has also to be considered.

III. POWER CONTROL STRATEGY

In order to find a suitable PC strategy, it must be considered that H/2 is not working in a licensed frequency band, which means uncoordinated H/2 systems might operate in the same area. Since the LA/PC algorithm is an implementation specific issue each manufacturer wants to ensure that the traffic handled by his equipment is served in a most efficient way. Therefore, the PC algorithm should not influence the transmission of its own packets (e.g. increase delay or PER). Nevertheless, the generated interference shall be reduced as much as possible. In the following an easy and efficient strategy is introduced, which fulfils these requirements [6]. In H/2 the MAC-Frames are used to organise the access on the shared physical medium. Using the maximum transmission power is assumed to result in a data rate that is higher than the required one. Thus, the MAC-Frame is only partly filled. This is indicated in Figure 2. Assuming an MT/AP is in the middle of the reception range of three other active devices that use the highest possible PHY-Mode and thus need to transmit with a respective high transmission power, the interference situation at the interfered device is rather fluctuating (cf. Figure 2). In [9] different strategies are discussed to distribute the *unused* parts within the MAC-Frame. Nevertheless, a major disadvantage of certain proposals is that the intensity of the interference changes significantly within the MAC-Frame, which makes the selection of the PHY-Mode more difficult. Thus, in the scenario in this paper one approach to be investigated is to distribute the generated interference more homogeneously.

An approach for this is shown in Figure 3. A combination of LA and PC can be used to reduce the *unused* parts of the MAC-Frame: As long as the MAC-Frame is not completely filled, the transmission power and the PHY-Mode are reduced. If more capacity is required than provided by a MAC-Frame (not all LCH packets can be transmitted), the transmission power is increased again so that a higher PHY-

Mode can be used, resulting in a higher data rate. Since a larger part of the MAC-Frame is used, the interference situation becomes steadier.

Furthermore, the combination of PC and LA enables a kind of *dynamic capacity assignment* between adjacent APs in order to satisfy required QoS parameters. APs with less traffic generate less interference and allow other APs to use a higher PHY-Mode with a higher data rate. In such a way, the system is facilitated to react more dynamically to the user's demand, which can be paid off in the negotiation of connection parameters and thus opens additional service options for QoS support. The aforementioned approach is illustrated in Figure 4, which shows a part of either the UL or DL phase (or both) of the H/2 MAC-Frame. We thereby assume that the AP basically wants to transmit/receive data of high priority. The unused part of the transport phase first shall be used to transmit data of low priority on a best effort basis (Fig.4a). In the beginning, the considered AP tries to achieve the highest possible throughput, thus transmissions take place using the highest PHY-Mode with a respective high signal power. As a consequence, the AP causes interference in adjacent cells, in which data transfer at a demanded QoS is not possible. The neighbouring APs hence signal this AP to exchange capacity with them. The procedure of this negotiation maybe applied via backbone signalling. However this is out of scope of this paper. Since the considered AP itself needs to ensure that its own high priority traffic is not interrupted, it proceeds by shifting resources from the best effort traffic to the high priority traffic (4b). Since the latter one now has more time within the MAC-Frame to transmit the respective data, our combined strategy for PC and LA can be applied again. In such a way, the high prioritised data can be further transmitted, but due to the lower transmission power needed, neighbouring cells are less interfered and now face the chance to realise data transfer at an appropriate higher level. If not all parts of the MAC-Frame of our AP are needed for the high priority traffic, the rest can be used to further transmit best effort traffic (4c). Obviously, this method is suited to transfer capacity between neighbouring APs, thereby considering certain QoS challenges as will be shown in the simulation section.

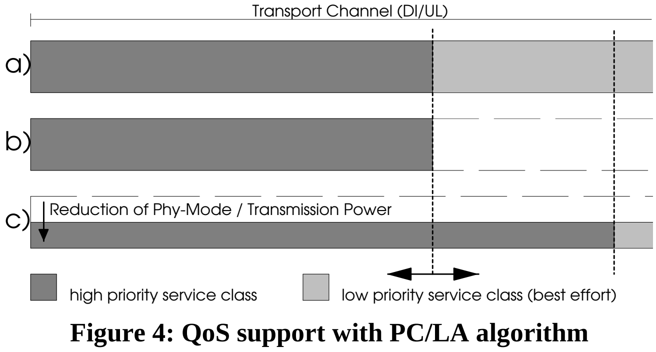

Figure 4: QoS support with PC/LA algorithm

IV. SIMULATION ENVIRONMENT

To evaluate the LA/PC strategy a simple scenario is considered consisting of seven micro cells with one AP each and a dynamic number of active MTs. Only the centric area is evaluated, whereas the remaining six cells are placed around in order to consider co-channel interference. The coverage area of a micro cell was chosen to a radius of 35m, whereby the APs are located in the centre. In each micro cell 500 terminals were uniformly distributed. Each MT is modelled as a two-state machine. During the active state, the load generator generates LCH packets using a Poisson arrival process while during the passive state no packets were generated at all. The MTs are supposed to be synchronised and all connections are symmetrical in up- and downlink. The duration of the on/off state is negative exponential distributed with a mean of 2s and 48s, respectively. In average 10 MTs were active. It is assumed that all APs/MTs were equipped with omni-directional antennas with no additional antenna gain. The pathloss is calculated by the following formula [4]:

$$L = 47 + 24 \log_{10} D \tag{1}$$

where D is the distance between sender and receiver. The mean C/I is calculated for each slot with all sending stations. A fading margin of 3dB is used.

V. TERMINAL SELECTION

An open point is the selection of the MTs for which the transmission power has to be adapted. To achieve the lowest possible interference in adjacent cells the transmission power at the border of the coverage area (cell) of the AP should be reduced first. MTs in the centre can use a higher transmission power since the attenuation towards stations in co-channel cells is higher. At the cell border more robust PHY-Modes usually must be used which offer a smaller range for power control. With regard to adjacent channel interference it is aimed to equalise the transmission power within the radio cell. Terminals may not apply the LA/PC at arbitrary times, e.g. the selection of a suitable MT must also consider the minimum interval between two power adjustments. To increase the data rate (and the transmission power) the selection is based on the following steps:

1. Only MTs that do not already use the highest PHY-Mode are considered
2. Power adjustment is possible (more than 20ms since the last update passed)
3. MTs with longest queue of waiting LCH packets
4. MTs with lowest transmission power

If the MAC-Frame is not completely filled and the data rate (and the transmission power) shall be reduced the MT is selected as follows:

1. Only MTs that do not already use the lowest PHY-Mode
2. Power adjustment is possible (more than 20ms since the last update passed)
3. MTs with highest transmission power

Due to the selection of the MT with the highest transmission power it can be expected that the MT with the largest distance to the AP is selected in reducing the power and the aforementioned criteria to reduce the transmission at the border of the coverage area is fulfilled.

VI. PERFORMANCE RESULTS

The *Grade of Service* (GoS) is used to determine the maximum load that can be carried. A small value of the GoS means a good grade of service for the system.

$$\mathrm{GoS} = \frac{\text{blocked setup trials} + 10 \cdot \text{lost connections}}{\text{total number of connections}} \quad (2)$$

A simple approach for Admission Control is used to determine if a connection can be accepted or not. When a connection request occurs (transition from the passive to the active state) the AP calculates the capacity, which is available if all active MTs transmitted with maximum transmission power. If the mean rate of all connections plus an overbooking of 10% is available the connection is accepted, otherwise it is rejected.

In Figure 5, the influence of PC on the GoS is shown. If no PC is used the average load per AP that can be carried by the system is around 5.6 Mbit/s. Using PC only in uplink direction leads to an improvement of around 15%. In case that also in downlink direction the transmission power can be adjusted separately for each MT - which is not foreseen in the H/2 standard so far - the load can be increased to around 6.8 Mbit/s (+21%). Figure 6 shows the probability of PHY-Modes to be used in a certain distance from the AP. First, one can clearly see circular sectors around the AP, each of which best served with a certain PHY-Mode. After applying our method, not only the overall transmission power was reduced, but also the PHY-Modes to be used. Now also the most robust PHY-Mode BPSK1/2 is used close to the AP. In Figure 7 the influence of the load on the transmission power is shown. First of all, it is visible that with increasing load the transmission power increases since higher PHY-Modes are selected to provide the required data rate. Furthermore, the transmission power increases with increasing distance between AP and MT. The algorithm to control the transmission power introduced in the previous section tries to select the same power for all MTs. But regarding to Figure 7 it can be seen that this target is not reached. The explanation can be found in the distribution of the PHY-Modes (Figure 6). At the border of the cell the interference condition allows only low PHY-Modes to be used. Thus the transmission power cannot be reduced that much. Closer to the AP higher PHY-Modes are used offering a larger range of power adjustments.

Finally, the fraction of the MAC-Frame, which is used for transmission, is discussed (cf. Figure 8). As already stated, PC/LA reduces the unused part of the MAC-Frame.

VII. DYNAMIC EXCHANGE OF CAPACITY AND QOS SUPPORT

In Section III we already indicated that the here presented interaction of PC/LA is also well suited for QoS support and dynamic capacity assignment respectively exchange between adjacent APs. Figure 9 shows the influence on traffic of the highest priority when applying our strategy. We assume two traffic classes to be transmitted as described previously, except for the curve on the very right side, for which only one priority class was assumed and which shall serve as a reference. The curves on the very left side and in the middle are derived from simulations with two traffic priorities. The curve on the left hand side thereby shows the dependency of the GoS related to Service Class (SC) 1 as a function of the

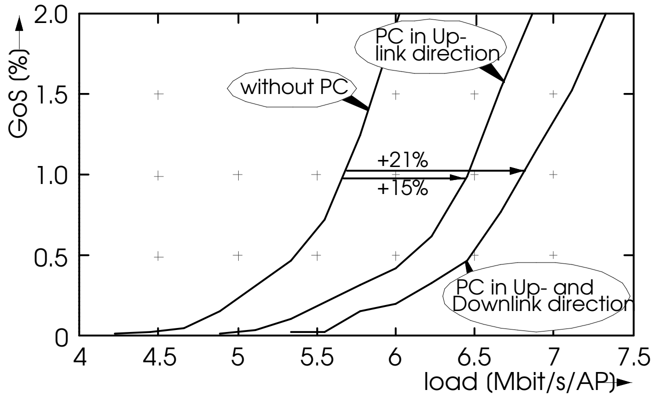

Figure 5: Grade of Service

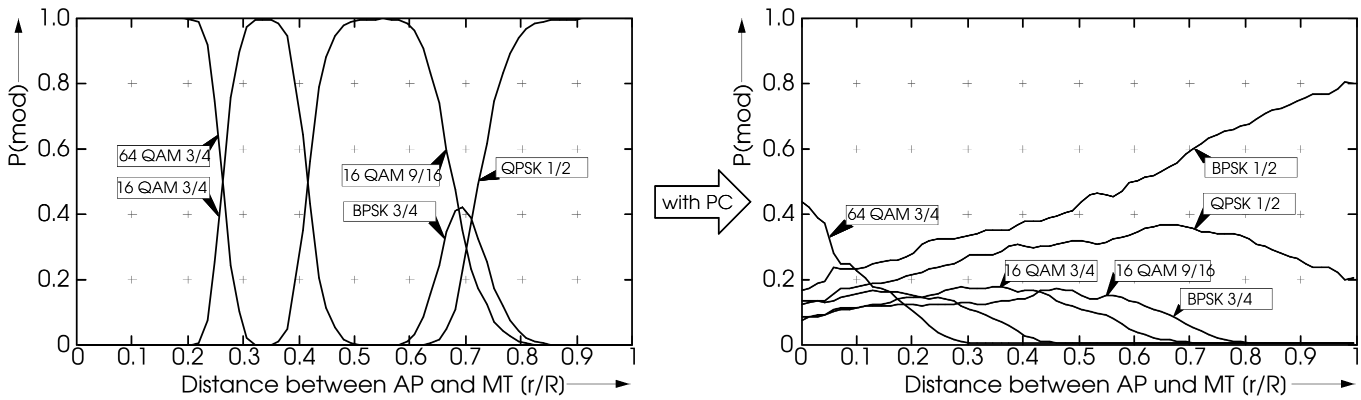

Figure 6: PHY-Mode distribution, R=35

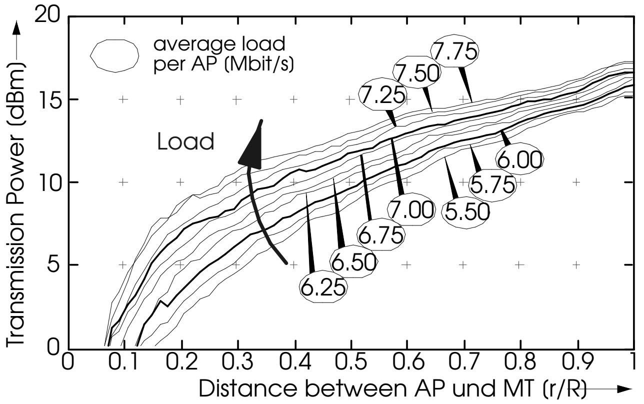

Figure 7: Influence of the load on the transmission power, R=35m

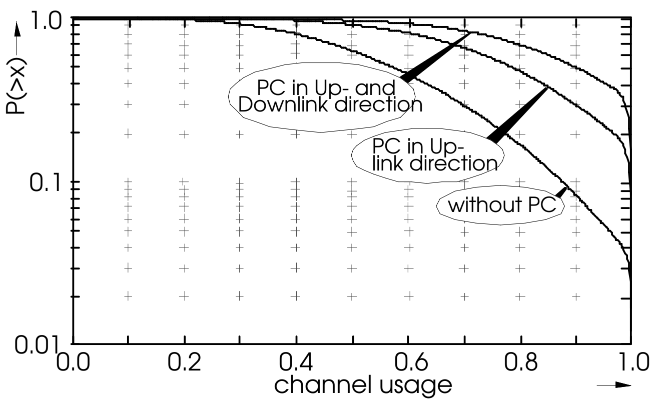

Figure 8: Usage of the MAC-Frame

load, if no combined PC/LA and dynamic capacity exchange is applied. One can see that a remarkable improvement takes place if the combined PC/LA is applied. E.g., regarding a load of 5.63 Mbit/s one can see that originally the GoS had a value of 2.12%, whereas after applying the presented strategy a value of only 1% attunes, which is an improvement of more than 50%! At the same time one can see, that the throughput of the SC1 at 1% GoS also could be increased from 5.33 Mbit/s to 5.51 Mbit/s, which after all is still a gain of 7%. However, the stability of the QoS related traffic is at the cost of the SC2 best effort traffic, which decreases from 7.30 Mbit/s to 5.45 Mbit/s.

VIII. SUMMARY

An easy to realise but efficient strategy for PC combination with LA for H/2 networks was presented. The approach is based on the idea to reduce the transmission power as long as the MAC-Frame is not completely used and to reduce the resulting interference in neighbouring cells. It was shown that the system capacity could be increased significantly in case of time variant load situations.

Additionally, this strategy is also suited to dynamically exchange capacity between APs. Especially, if different priorities of data traffic need to be supported, the presented method has the potential to not only ensure QoS connections, but also allows a slight increase of the overall system

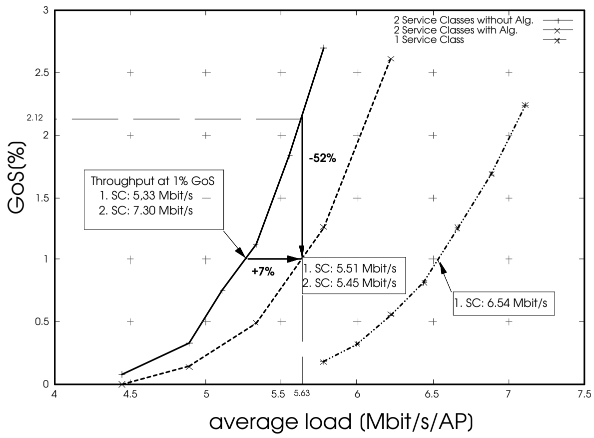

Figure 9: GoS for traffic of Service Class 1

throughput of high priority traffic though on the cost of lower prioritized data. Further investigations will consider more sophisticated approaches of this method, including delay requirements when increasing the transmission power.

REFERENCES

[1] Broadband Radio Access Networks (BRAN) ETSI TS 101 475 v1.2.2, HIPERLAN Type 2; Physical (PHY) layer, February 2001.

[2] Broadband Radio Access Networks (BRAN) ETSI TS 101 761-1 v1.2.1, HIPERLAN Type 2; Data Link Control (DLC) Layer specification; Part 1: Basic Data Transport Functions, November 2000.

[3] Broadband Radio Access Networks (BRAN) ETSI TS 101 761-2 v1.2.1, HIPERLAN Type 2; Data Link Control (DLC) Layer specification; Part 2: Radio Link Control (RLC) sub-layer, April 2001.

[4] BRAIN: Broadband Radio Access for IP based Networks IST-1999-10050, “Technical requirements and identification of necessary enhancements for HIPERLAN Type 2”, IST-1999-10050 BRAIN D3.1, Sept. 2000.

[5] BRAIN: Broadband Radio Access for IP based Networks IST-1999-10050, “Performance of the BRAIN Air Interface: Simulation Results and Proposed System Optimisation for the Standardisation Process”, IST-1999-10050 BRAIN D3.2, March 2001.

[6] A. Krämling, “A Power Control Strategy for HIPERLAN/2”, Proc. of the 10th Aachen Symposium on Signal Theory, ISBN 3-8007-2610-6, Sept. 2001, pp 203-208, Aachen, Germany

[7] Broadband Radio Access Networks (BRAN) ETSI TS 101 761-2 v1.2.1, HIPERLAN Type 2; Data Link Control (DLC) Layer specification; Part 2: Radio Link Control (RLC) sub-layer, April 2001.

[8] Z. Lin, G. Malmgren, and J. Torsner, “System Performance Analysis of Link Adaptation in HiperLAN Type 2“, Proc. of IEEE 50th Vehicular Technology Conference (VTC) 2000 (Fall), Boston, MA, September 2000, pp.1719-1725.

[9] J. Rapp, “Hiperlan/2 system throughput and QoS with interference improving strategies”, Proc. of IEEE VTS 53rd, Vehicular Technology Conference, Spring, Rhodes, Greece, May 2001, Paper 243.

[10] MIND: Mobile IP based Network Developments (IST-2000-28584), http://www.ist-mind.org/

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