Performance of a hybrid TDD-CDMA system with random slot allocation (RSA) in comparison with an equivalent FDD-CDMA system

C. Evers*, R. Esmailzadeh†, H. Haas*, M. Nakagawa†

*School of Engineering and Science
International University Bremen
28759 Bremen, Germany
Email: c.evers@iu-bremen.de
†Department of Information and Computer Science
Keio University
Yokohama 223-8522, Japan

***Abstract*— This paper proposes a hybrid form of ad-hoc networking where the public network frequency and technology is re-used to establish an ad-hoc network. The proposed technology is TD-CDMA, which will be used for both public and ad-hoc in the same frequency band. In particular, this paper treats the performance difference between a hybrid public & ad-hoc TDD-CDMA system employing random slot assignment, an equivalent TDD-CDMA system without any extra ad-hoc interference and an equivalent FDD-CDMA system. It will be shown that the additional interference on the hybrid system caused by the private ad-hoc network is minimal. Furthermore, it will be demonstrated that the performance of the hybrid TDD system outperforms the FDD mode.**

I. Introduction

In cellular communications systems, a base station (BS) serves multiple users in a star-topology basis, where the BS is delivering data and voice packets to the mobile user equipment (UE). In Ad-Hoc networks, a central BS is not necessary; mobile stations (MS) communicate either directly with each other or indirectly through other users, respectively by exploiting a nearby BS. The connection to other networks may occur by wired or wireless means. Furthermore, amongst other applications, the ad-hoc mode can be operated between users close to each other, peripherals, and UEs (such as mouse, headset etc.), or simply in situations where a user is better located to connect to a central system [1].

The co-existence of wireless communications networks in public networks delivers additional service and reduces the system load on the BS of the public network. Where central, cellular operation is either impossible or inefficient, ad-hoc systems have been designed to take over communications.

These hybrid networks have been realized so far by operating the ad-hoc system in the unlicensed band. This results in dual-mode devices of high cost, as they have to be capable of operating in and handing over between the licensed band of the cellular network and the unlicensed band used by the ad-hoc network [2][3].

This paper proposes a method such that the ad-hoc network reuses the band of the cellular network this concept is referred to as TDD underlay [4]. As the time-slot structure of TDD-CDMA offers great flexibility for dynamical resource allocation and power control, this method is based on TDD-CDMA [5],[6]. Further, random slot allocation (RSA) [7] is applied, as it was shown to improve the overall system performance. The paper focuses on a comparison of the randomized TDD-CDMA system to an equivalent FDD-CDMA system.

We realize that there are still questions with TDD-CDMA operation. Although these have generally been resolved, we still encounter issues such as how all cells in a TDD-CDMA are synchronized, how various TDD-CDMA operators need to be coordinated, etc. As for the ad-hoc system proposed in this paper, similar questions arise as to why an operator would allow its spectrum to be reused. Notwithstanding these issues, we propose this conjoint public ad-hoc system, as we believe the advantages offered by this technique warrant it to be closely examined.

The paper is structured as follows: Section II outlines the system model, followed by Section III depicting the results. Section IV documents the conclusions.

II. System Model

The following sections will document the characteristics of the simulation. Differences in the setup of the simulatio for the system with and without ad-hoc will be outlined and system parameters given.

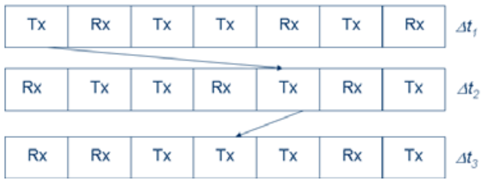


Fig. 1. RTO Algorithm

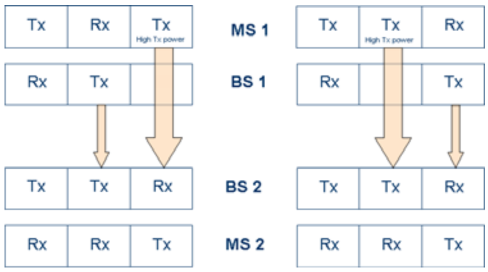


Fig. 2. Interference scenario before (left) and after (right) TS-opposing size of arrows indicates potential severity of Interference

A. Cellular Layout

The cell setup consists of a central cell surrounded by two tiers, i.e. a total of 19 cells. As the system is based on the UTRA-TDD air interface, the frame length is 10ms, where one frame consists of 16 time slots (TS) [1]. Each TS is designated for either up- or downlink and can accomodate 12 user codes. The granularity of the system is defined by frame / TS / code, which is defined as one resource unit (RU). Hence, as a frame consists of 16 TS and each TS accommodates 12 user codes, 192 RUs are available per frame.

B. Random Slot Allocation

As shown in [7], time hopping improves the overall system performance tremendously. Thus, the system model in this paper uses RSA for both public and ad-hoc network. In the following, the random time hopping methods for both networks will be outlined.

1) Public Network: Figure 1 and Figure 2 show the principle of the RSA algorithm. Every Δt, the order of the time slots within one frame will be permuted randomly. Therefore, the probability of a transmitting station with high transmit power in the same TS as a receiving station of another cell is reduced. This principle is shown in Figure 1 and Figure 2. In order to produce high interference, users have to fulfill the following four conditions at the same time: They have to

1) be close to each other,
2) be active at the same time,
3) have high transmit power, and
4) be of opposite slot assignment.

[1]The authors are aware of the fact that UTRA-TDD has only 15 TS. However, in order to compare the results to a UL/DL-symmetric system like FDD, a number of TS divisible by 2 is required. This change does not influence the outcome of the study.

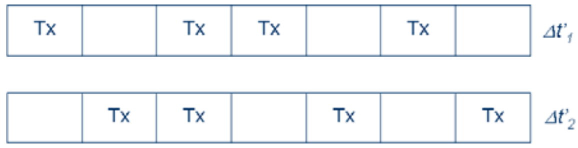


Fig. 3. Random Time Slot Assignment for ad-hoc users

As the probability of all four conditions being fulfilled at once is considerably low, interference is minimized by the means of randomness and hence the overall system performance is improved.

2) Ad-Hoc Network: In this simulation, ad-hoc pairs are uniformly distributed in the cells of the public system. One particular user per ad-hoc pair is defined as the transmitting user, while the other is the receiving user. Once set, this arrangement cannot be changed anymore, i.e. the transmitter will be transmitting to the receiver whenever the pair is active, whereas the receiver can never transmit packets to the transmitting station. Data exchange only occurs in a preset number of time slots. After each frame, the order of the TS will be permuted according to the principle shown in Figure 3. Hence, the probability of a constant interference between a receiving user in the public system and the transmitting station of an ad-hoc pair is minimized and randomness of the system maintained. In the following, the transmitting ad-hoc user will be defined as the master and the receiving as the slave.

C. Traffic Model

In the following, two traffic models will be considered for different parts of the simulation. For the reproduction of the RSA algorithm, a traffic model incorporating data and voice will be considered, whereas a traffic model with only data users will be assumed for simplicity for the simulations afterwards. This simplification will not influence the relationship between uplink (UL) and downlink (DL) interference, as voice is a symmetric service, i.e. requires one RU for UL and one for DL. In any case, regardless of the actual traffic model, the call arrival rate of the system is assumed to be Poisson distributed.

The different interarrival times for the public and ad-hoc network will be outlined in the following two sections.

1) Public Network: The inter-arrival rate λ_{public} is calculated by

$$\lambda_{public} = \frac{\mu_{public}}{100} n_{ch} n_{cl} \frac{\Delta t}{m_{ht}} \quad (1)$$

where μ is the offered mean system load in percent, n_{ch} the total number of duplex channels for a particular service, n_{cl} the number of cells in the service area, Δt the simulation clock, and m_{ht} the mean holding time. The latter is negatively exponentially distributed. n_{ch} in this case is dependent on the number of RUs required per service as will be outlined in Section II-D.1 [7].

2) Ad-Hoc Network: Usually, the system is 100% loaded if all 12 codes in the 16 TS are occupied all times. However, for simplicity, in this simulation, a loading of 100% is defined as the occupation of one user code per TS. Hence, when using eqn. (1) as the interarrival rate for the ad-hoc network, it is found that $n_{ch_{adhoc}} = 16$.

D. Channel Asymmetry

Voice is considered to be a symmetric service, i.e. one RU is required for each UL and DL, whereas data is asymmetric and hence the number of RUs required for the respective link is not known *a priori* but rather set as a parameter. The following three sections will outline the channel asymmetry models for the public network using data and voice traffic as well as only data traffic, and the ad-hoc network.

1) Public Network: Using data and voice traffic: Adding up voice and data channels yields the total number of channels available:

$$n_{ch}^{tot} = n_{ch}^{v} + n_{ch}^{d} \quad (2)$$

where n_{ch}^{v} is the total number of voice channels and n_{ch}^{d} the total number of data channels. The ratio of voice to data channels is given by η. Using this definition and taking into account that each service requires a different number of RUs, n_{ch}^{v} and n_{ch}^{d} are found by

$$n_{ch}^{v} = \frac{n_{ru}}{n_v + \frac{1-\eta}{\eta} n_d} \quad (3)$$

$$n_{ch}^{d} = \frac{n_{ru}}{n_d + \frac{1-\eta}{\eta} n_v} \quad (4)$$

where n_{ru} is the maximum number of available RUs and n_v, n_d the total number of RUs required for voice and data respectively. In the case of voice, the parameter μ is introduced in order to model the traffic imbalance. μ can only be a positive integer and is denoted by

$$\lceil \mu \rceil = \frac{n_a^d}{n_b^d} \quad (5)$$

where a and b denote either UL or DL, such that $n_d^a \geq n_b^d$. Therefore, if the same rate of asymmetry is applied, an asymmetry favoring DL is treated exactly like an asymmetry favoring UL, and vice versa. Hence, the total number of RUs required for link direction a can be calculated as follows:

$$n_a = n_{ch}^{v} + n_{ch}^{d} \mu \quad (6)$$

And thus, the total number of RUs required for link direction b are given by:

$$n_b = n_{ru} - n_a \quad (7)$$

In order to ensure the full exploitation of the spectrum, n_a must be a multiple of the maximum number codes per TS. In order to simplify the notation for channel asymmetry, in the following, the asymmetry is denoted by a ratio $x : y$, where x is always associated with the DL [7].

Using only data traffic:: As voice is a symmetric service and will thus marginally influence the outcome of the simulation, for simplicity only data traffic is taken into account in the simulation. For the implementation of the public network, only data calls will be considered for the simulation. Hence, as

$$\eta = \frac{n_{ch}^{v}}{n_{ch}^{tot}} \quad (8)$$

and as in this simulation, $n_{ch}^{v} = 0$, it follows that $\eta = 0$, and hence, n_{ch}^{d} is found by

$$n_{ch}^{d} = \frac{n_{ru}}{n_d} \quad (9)$$

Therefore,

$$n_a = n_{ch}^{d} \cdot \mu \quad (10)$$

Substituting eqn. (9) into (10),

$$n_a = \frac{n_{ru}}{n_d} \cdot \mu \quad (11)$$

and hence,

$$n_b = n_{ru} - n_a = n_{ru} - \frac{n_{ru}}{n_d} \cdot \mu \quad (12)$$

2) Ad-Hoc Network: In the ad-hoc network, a data call is considered to occupy one RU in the DL. Thus, the number of RUs available in the case of ad-hoc is

$$n_{ch_{adhoc}}^{d} = \frac{n_{ru}}{n_d} = \frac{n_{ru}}{1} = n_{ru} = 192 \quad (13)$$

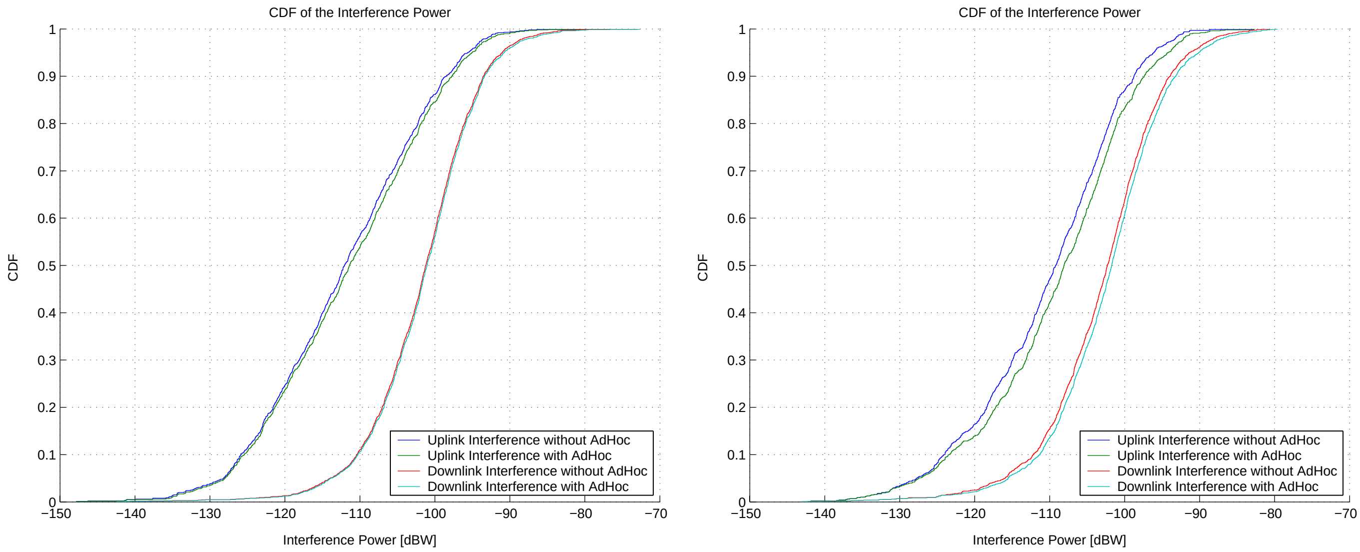
Hence, 192 data call are possible and will result in full system load. As mentioned in Section II-C.2, however, in this simulation, at maximum 16 RUs will be occupied by an ad-hoc user.

E. Power Control

A slow signal-to-interference ratio (SIR)-based power control (PC) method is used to adjust the transmit power levels. Since fast fading effects are neglected, the fast power control on a frame basis, as normally used in UTRA-TDD, does not need to be considered [7].

F. Handover Model

For those parts of the simulation, where mobility was applied, a simplified inter-cell handover algorithm is used. This algorithm bases its handover decision on the received signal strength (the signal strength is determined by the pathloss of the shadowing) on the common control physical channel (CCPCH) which carries the broadcast channel (BCH). The handover process is initiated when the received signal



(a) TDD-CDMA UL vs. DL interference of cellular and hybrid system; adhoc load 40%

(b) TDD-CDMA interference of cellular and hybrid system; ad-hoc load 100%

Fig. 4. Interference Power in TDD-CDMA Systems

strength of the CCPCH of a neighbouring cell exceeds the signal strength of the CCPCH of the own cell by at least 3dB (handover margin). The handover is carried out under the provision that the neighbouring cell can offer a free channel. Should this, however, not be the case, the call will still remain served by the initial BS. Thus, dropped calls due to handover failures will not occur, which, in turn, means that the signal quality of the respective user might degrade below a required threshold and that the overall interference in the system reached high levels. As a consequence, the interference reported in Section III are pessimistic [7].

G. System Parameters

The parameters that have been used are documented in Table I.

III. Results

Figures 4 and 5 show the simulation results for the TDD-CDMA and a fixed-channel assignment (FCA) algorithm resembling an equivalent FDD system. In the FCA case, the sending ad-hoc user transmits data in the UL slots and the receiving user operates in the DL slots. The graphs show the overall system performance, that of the ad-hoc network operating in the DL and that of the ad-hoc network operating in the uplink.

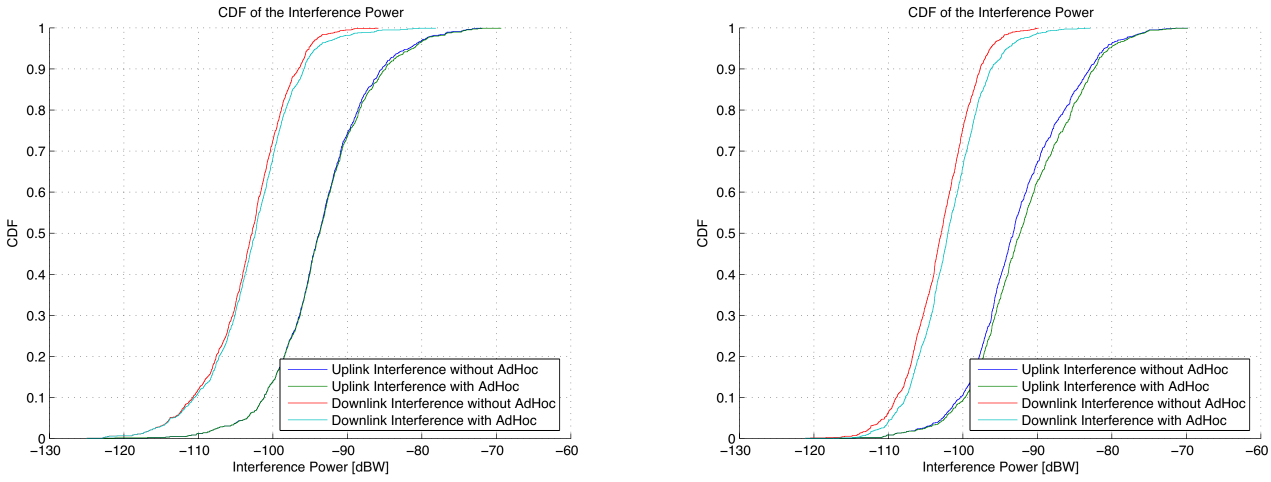
Figure 4 depicts the results for the fully randomized TDD-CDMA system. The median of the interference power of the UL (at the cellular BS) is approximately -112dBW, whereas the DL (at the cellular MSs) has a median of

TABLE I

Simulation Parameters

Parameter	Value
Mobile Speed	3km/h
Handover Margin	3dB
C/I based power control target	-5dB
Dynamic range of power control	80dB
Std. dev. of lognormal shadowing - outdoor	6dB
Std. dev. of lognormal shadowing - indoor	8dB
Std. dev. of lognormal shadowing - ad-hoc	2dB
Cell radius - outdoor	1000m
Cell radius - indoor	50m
Number of interfering tiers	2
Max. Tx power per slot - public	13dBm
Max. Tx power per slot - adh-hoc	3dBm
Number of RUs for voice	1:1
Number of RUs for data	3:1
TS opposing frequency	1Hz
Mean holding time	120s
Antenna gain (both BS and MS)	2dBi
Spreading Code Length	12dB
Required SNR	7dB

102dBW. As can be observed from the figures, the increase of interference power caused by the ad-hoc system is clearly dependent on the load and hence traffic within the ad-hoc network. It ranges between 0.5dB for 10% of load and 2dB (1.5% of the total interference power of the hybrid system) for 100% load, if 1 user code per TS can be occupied in the ad-hoc network. As for the FDD-CDMA system where the



(a) FDD-CDMA UL vs. DL interference of cellular and hybrid system; ad-hoc load 50%

(b) FDD-CDMA UL vs. DL interference of cellular and hybrid network; ad-hoc load 100%

Fig. 5. Interference Power in FDD-CDMA Systems

cellular system alone has a median interference power in UL of -92dBW and -102dBW in DL a maximum of additional interference caused by the ad-hoc network is found to be 2.5dB (90% of ad-hoc network load), as outlined in Figure 5(b). A load of 50% accords to an additional interference of 1dB (Figure 5(a)). The difference of median interference power in UL between the TDD and FDD is found to be 20dBW. TDD therefore clearly outperforms FDD.

Furthermore, it is to be observed that the DL in the TDD-CDMA system is more affected by interference than the UL, whereas this order reverses for the FDD-CDMA system. This can be explained as follows: channel asymmetry is assumed for the TDD system, while FDD is UL-DL symmetric. Hence, for the dominant link in TDD i.e. DL the number of users increases and therefore the interference is increased, which leads to an inversion of the order of UL and DL statistics of the TDD system with respect to FDD.

IV. Conclusion

It was shown that RSA is an efficient measure to improve the system performance of a hybrid network. What is more, it turned out to outrun a hybrid FDD-system with randomized ad-hoc network. Further, for both systems, it has been shown that the implementation of a randomized ad-hoc network reusing the band of the cellular system, does not influence the total system performance significantly (increase of total interference by approximately 1.5% for TDD-CDMA, 2% for FDD-CDMA). Hence, the interference power of the simulated hybrid network is kept at a minimum.

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