ENHANCED RADIO RESOURCE MANAGEMENT INTRODUCING SMART DIRECT LINK CONCEPTS

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***Abstract** – This paper investigates an enhanced radio resource management scheme in centralised controlled radio cells. It thereby introduces a new scheduling approach for resource grants with a special focus on the appliance of direct terminal-to-terminal operation as offered by various upcoming wireless broadband communication systems. In order to obtain a more efficient use of available resources, solutions have to be found, how resources in self-organising radio systems can be used in parallel by applying direct link communication between mobile terminals. The decision about multiple assignments of the same resources is performed by a central instance considering the interference situation within the cell. The combination of the direct link communication and the sophisticated scheduling under the control of a central instance is referred to as 'Smart' Direct Link (SDiL) appliance. Performance simulations for this novel concept indicate large gains when applied to specific scenarios.*

I. Introduction

A fundamental problem of operating wireless radio systems is to organise and to control the assignment of radio resources. For the transmission of data the resources are physically represented by separated, orthogonal transmission units. The orthogonality is given either in the frequency domain, time domain, code domain, space domain, or a mixture of the aforementioned. In cellular radio systems the assignment of radio resources is supervised and controlled by a central instance. In many systems, e.g. GSM or UMTS, communication takes place between the Mobile Terminals (MTs) and the central instance. However, other (self-organising) radio systems also permit direct communication between MTs and do not necessarily integrate a central instance to control the medium access. For example in radio systems implying the legacy IEEE 802.11 [1] standard, no central organised assignment of radio resources is required. The medium access control (MAC) is decentralised, making an optimal utilisation of available resources difficult. Using a central instance for the controlling of the medium access (centralised MAC) and the resource assignment, like in HIPERLAN/2 (H/2) [2], has the potential of a more purposeful and thus more efficient use of resources.

Considering a centralised MAC, the scheduler of the central instance usually grants an exclusive transmission right to a respective MT, regardless whether this is for a direct terminal-terminal communication or a transmission between the MT and the central instance. Thus, the same resource usually is not assigned in parallel several times. An exception to this may apply to systems that integrate several transceivers per cell and sectorisation. One proposal on applied Space Division Multiple Access (SDMA) techniques is found in [3]. However, those approaches rely on smart antenna technology and beamforming. The same resource (frequency) can be allocated for systems using SDMA schemes, by exploring orthogonality in the space domain. However, this is not directly applicable to central instances using omnidirectional antennas, as regarded here. Furthermore, these approaches do not consider mutual interference from communicating MTs using the direct mode. The parallel usage of same resources during the transmission of data between different pairs of communication partners generally leads to interference and/or to mutual disturbances of the respective transmissions. In Spatial Time Division Multiple Access (STDMA), the Multiple Access Interference (MAI) in a slotted and framed system is managed in a distributed way [4], [5]. STDMA is a generalisation of the TDMA protocol for multihop networks where slots are allocated to a set of non-interfering transmissions. Based on a so-called compatibility matrix, which indicates links that can be simultaneously enabled without causing a collision at either of their respective destinations in the network, a schedule is defined. This approach provides a general methodology to assign resources in a slotted system. However, it requires a lot of information at each node because of its distributed character. Furthermore, it assumes a synchronised system because of the slot and frame structure. In contrast to STDMA and a distributed assignment of resources, the SDiL appliance envisages that resources in self-organising radio systems with direct link communication between mobile terminals are assigned, supervised and controlled by a central instance. Moreover, no slotted operation is required, since the synchronisation of the assignment is guaranteed by the central instance.

In the following Section II, the conceptional approach for the efficient usage of available resources is explained in detail. Section III includes a performance estimation of the SDiL scheduling compared to conventional DiL scheduling schemes. Finally, a conclusion can be found in Section IV.

II. Conceptional Approach

In the following, a concept for multiple allocations of resources is presented, especially considering pathloss properties within a given scenario. Since this approach incorporates direct link communication and sophisticated scheduling, the concept is also referred to as 'Smart' Direct Link (SDiL) appliance.

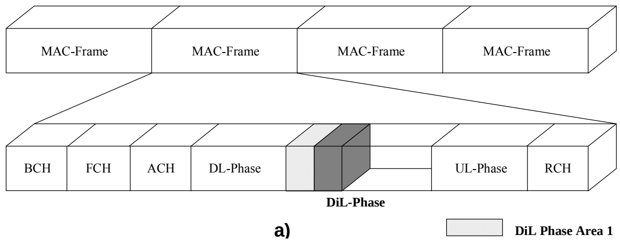

Figure 1: Conventional and Smart Appliance of DiL

a) Conventional resource allocation

First, in this section conventional radio resource allocation from a cellular as well as from a legacy IEEE 802.11 perspective is discussed. Afterwards, H/2 is examined with a special focus on applying direct link principles. In cellular mobile radio systems the same resources can be used several times by reusing the same frequencies in different cells (frequency reuse) while ensuring sufficient reuse distance. From a global system point of view, the same resources are used multiple times [6][7]. If the same frequency is used within each cell, especially MTs at the cell border will substantially suffer from interference. One method to provide sufficient reuse is to arrange cells in clusters. Thereby, each cell is working on orthogonal channels (e.g. frequencies), mitigating detrimental interference at the cell boundaries. The number of cells in a cluster is called *cluster size*. Repeating this cluster structure by an appropriate spatial arrangement, i.e. tessellation, over the entire cellular system ensures that two cells using the same frequency are spatially separated by at least one orthogonal channel.

In self-organising networks using the IEEE 802.11 standard, the assignment and/or allocation of resources for communication between MTs takes place without the support of a central instance. The MAC is based on the multiple access procedure CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). This is how stations, which lie in the range of each other, shall not disturb each other's transmission by using the same resources. If some other stations that are not in the reception range also want to transmit data, they can use the same resource since the medium was measured to be idle before. In this case the same resources are used in parallel. Thus, within IEEE 802.11 a multiple reservation of resources is possible. However, the allocation was not coordinated/optimised and this most probably results in an inefficient usage of available resources, e.g. spatially separated stations using the same frequency use the same resource: In the optimum case they are located in the frequency reuse distance as known from cellular systems. However, if their distance is a bit higher, their transmissions block other stations in between from using the same resource. Seen from an overall system point of view, this results in the aforementioned ineffective use of the spectrum. Furthermore it is hard to introduce power control since, this conflicts with floor acquisition (RTS/CTS) that protects communication from disturbances, especially in partially connected networks with hidden stations.

In H/2, central instances are used for the assignment of resources. If a binding exists to a fixed network, then this instance is called Access Point (AP). If no infrastructure is present, a so called Central Controller (CC) takes over the tasks of the AP. The AP/CC thus takes over the controlling of the communication of all MTs within its range. The organisation of the transmission in H/2 is TDMA based. The resource available for transmission is divided into so-called MAC frames, see Figure 1, each of which with a duration of 2 ms.

A MAC frame starts with the Broadcast CHannel (BCH), which contains a special synchronisation sequence as well as general cell related information. With the following Frame CHannel (FCH), each MT associated to a CC is provided the information, at which time in the DownLink phase (DL phase) it must receive data from the CC and at which time in the UpLink phase (UL phase) it may send data to the CC. Direct communication between MTs takes place in the Direct Link phase (DiL phase) [8]. The beginning of the respective transmissions in the DiL phase is likewise indicated by time pointers within the FCH. MTs may request for transmission opportunities either in the DiL phase or in the UL phase by sending a 'capacity request' in a time slot of the Random access CHannel (RCH). In the following MAC frame they are informed via the Access feedback CHannel (ACH) whether their request was received without errors or whether it was interfered and thus needs to be retransmitted. All transmissions in the DL, DiL or UL phases are scheduled in such a way that no transmissions between two communication partners, which are assigned to the same CC, take place at the same time. Thus, for all transmissions between MTs and their CC as well as for the direct transmissions between MTs, no resources are used in parallel. Multiple reservations of resources are only possible if MTs are assigned to different APs/CCs. In this case coincidentally the same transmission time points might be scheduled. If those MTs are not too far away from each other, mutual disturbances of the transmissions may occur.

b) Smart Direct Link Appliance with multiple resource grant

In the following, the focus is on the scenario as shown in Figure 2. The AP/CC controls the radio medium and thus communication between CC and its associated MTs as well as direct communication between the MTs. The aim is to perform a smart scheduling in such a way that resources are assigned in parallel. A special focus thereby lies on the appliance of direct link connections.

Preconditions for SDiL appliance

If SDiL shall be applied, the CC needs to know about the interference situation at each of its MTs' position. This information can be obtained at the CC, e.g. by signalling from the MTs. For that purpose the H/2 standard defines procedures that allow MTs to determine interference and link-conditions and to report measurements to the CC. Though these measurements are intended for dynamic frequency selection and handover preparation, they can also be used for SDiL scheduling decisions. Additionally, the CC may consider the current position of each MT. This comprises both, the distance between CC and MT as well the azimuth information. For the first, the AP can rely on own measurements, estimating the distance with the help of the pathloss of the signal. For the second, the CC may again rely on the MTs' measurements. Like the CC, each MT discovers its attainable neighbours and announces their distances to the CC, which now is able to determine the azimuth information by triangle calculation. Based on these location- and interference distribution information, the CC knows, which MTs are in the coverage area of each other and thus could apply direct mode communication, respectively, which MTs would disturb each other if the same resource was used simultaneously. Seen from the opposite side, it is also well-known which MTs are not in mutual reception range and thus would not disturb each other. For a proper SDiL scheduling, the CC needs to administer and trigger an update of those information on a regular basis. If different couples of MTs then request direct communication, the scheduler of the CC may resort to that information in order to multiply grant the same resource, compare Figure 2.

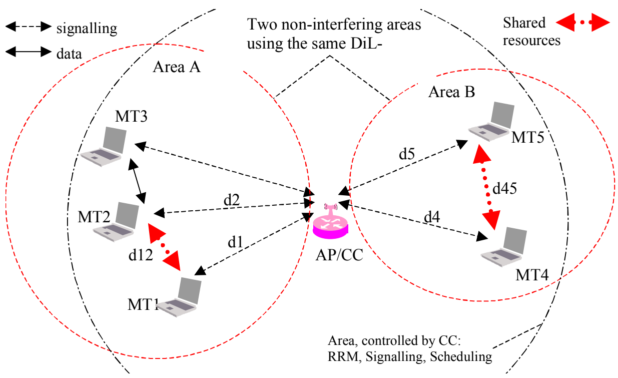

Figure 2: Parallel usage of resources

Realisation of the SDiL concept

As said before, (direct) communication between two MTs or several MTs (multicast) is organised by the CC. If an MT wants to transmit data to another MT within its coverage area, it may request for (DiL) resources. However, it could also be up to the CC to decide whether centralised mode (data transfer via the CC) or direct mode shall be applied. The latter means, that due to its location- and interference distribution information, the CC could propose the requesting MT to establish a DiL, though the original request was for a centralised mode data transfer. Assuming a scenario like in Figure 2, the CC may then perform SDiL scheduling. In H/2, the parallel assignment can easily be realised and signalled within the FCH whereby not even a modification of the standard would be necessary: By indicating the same starting point of time to different MT couples, which are to use the same resource, the appropriate transmissions in the DiL phase take place at the same time, see Figure 1b, which illustrates the respective structure of the MAC frame. The duration of the simultaneous transmission not necessarily needs to be of the same length. However, for certain reasons like simplification of scheduling it might be advantageous, if the durations of a parallel resource usage of different communication partners are of the same length. In this case, further sophisticated approaches like in [9], which propose a combination of power control and link adaptation, can be used for adjusting the transmission time periods within the parallel DiL phase.

It shall be mentioned that the halved sized drawing of the parallel transmission in Figure 1b does not mean, that either transmission may only make use of half of the (channel) capacity.

The following section presents performance estimations for both scheduling concepts, DiL and SDiL.

III. Performance Estimation

In general, the energy arriving at the receiver can be calculated by [10]:

$$P_R = g_T\, g_R\, P_T \cdot \left(\frac{\lambda}{4\pi}\right)^2 \cdot \frac{1}{d^{\gamma}}, \qquad (1)$$

whereby P_T represents the power radiated by the transmitter and P_R the input power at the receiver, g_T and g_R stand for the corresponding antenna gains, λ is the wavelength and d the distance between sender and receiver. In order to distinguish between certain environments, the propagation coefficient γ was introduced with values between 2 (free-space propagation) and 5 (strong attenuation). Given a logarithmic presentation of (1) leads to:

$$P_R\,[dB] = 10\lg(g_T) + 10\lg(g_R) + 10\lg(P_T) + 20\lg\left(\frac{\lambda}{4\pi}\right) - 10\gamma\lg(d). \qquad (2)$$

Since no additional antenna gain is assumed and H/2 operates at frequencies f=c/λ of 5 GHz, equation (2) can be further simplified to:

$$P_R\,[dB] = 23dBm - 46{,}42dB - 10\gamma\lg(d), \qquad (3)$$

whereby a transmit power of $P_T = 200mW$ was assumed. Table 1 summarises all general assumptions for the here investigated cases:

Table 1: Parameter Overview

Parameter	**Variable**	**Value**
Transmit Power	P_T	23 dBm
Noise power	N	-90 dBm
Propagation coefficient	γ	2,5
Distance MT_1-MT_2	d_{12} (= d_{45})	15 m
Distance $MT_{1,2}$-$MT_{4,5}$	d_{AB}	150 m
Frequency	f	5 GHz

For conventional appliance of DiL, the received signal is only disturbed by background noise, if no further co-channel interferers are present. Thus, the quality of the received signal can be determined to:

$$(C/N)_{DiL_{12|45}} = 23dBm - 46{,}42dB - 10\gamma\lg(d_{12|45}) + 90\,dBm$$
$$= 66{,}58dB - 10\gamma\lg(d_{12|45}). \qquad (4)$$

In order to derive a respective formula for the SDiL, the self-interference due to the parallel scheduling needs to be considered, which means a SDiL transmission between MT1↔MT2 will impact a respective SDiL between MT4↔MT5 and vice versa. For small distances $d_{12} \ll d_1, d_2$ and $d_{45} \ll d_4, d_5$, it is assumed for simplification that the interferer/interfered MT is located in the middle of the two communicating parties, see Figure 3.

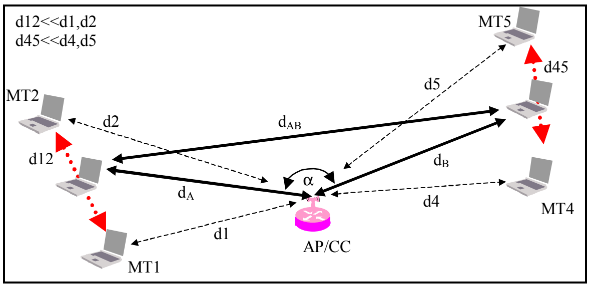

Figure 3: Self-interference for SDiL appliance

Under this assumption, the distances d_A and d_B may be approximated with $d_A = (d_1+d_2)/2$ and $d_B = (d_4+d_5)/2$. The distance d_{AB} between these two substitutes calculates with the law of cosines,

$$d_{AB} = \sqrt{d_A^2 + d_B^2 - 2 d_A d_B \cos\alpha}\,, \qquad (5)$$

and the reception quality for the SDiL is determined by

$$(C/(I+N))_{SDiL_{12|45}} = 23dBm - 46{,}42dB - 10\gamma\lg(d_{12|45})$$
$$-10\lg\left(10^{(2{,}3dBm - 4{,}642dB - \gamma\log(d_{AB}))} + 10^{-9{,}0}\,mW\right) \qquad (6)$$

Investigations in [11] include results for the H/2 system throughput as a function of the receive power budget C/I (C/(I+N)), see Figure 4. The reception quality of the signal and the chosen Phy-mode result in an end-to-end user data rate. If the offered load is high enough and the MAC frame is completely used, a maximum system throughput depending on the Phy-mode adjusts.

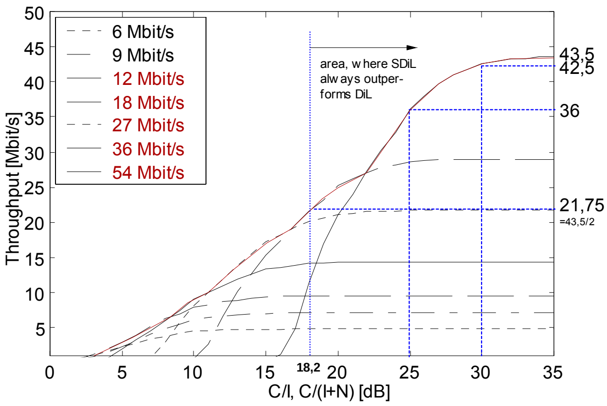

Figure 4: H/2 max. system throughput for resp. Phy-modi

Since the various Phy-modi perform differently with respect to the signal quality, transmission errors result in necessary retransmissions. This signalling overhead is also considered in the throughput curves of Figure 4. Thus, applying a link adaptation scheme that dynamically chooses the best Phy-mode with respect to the throughput will allow realising the indicated data-rates.

Figure 5 and Figure 6 show the characteristic of the conventional DiL appliance represented by the C/N curves in comparison to the presented SDiL proposal, represented by the C/(N+I) curves. For these results the initial parameter settings from Table 1 have been assumed. One can see, that simulation results and analytical investigations map quite well.

The curves in Figure 5 point out the influence of the distance d_{12} (d_{45}) of the communicating MTs on the quality of the received signal. As expected, the quality deteriorates on increasing the distance. Additionally, the influence of the distance d_{AB} to the respective other communicating couple was considered showing an approximation of the receive power budget for the two DiL variants. The results for increasing distances d_{AB} indicate that SDiL will perform best when applied in larger cells or at the border of a cell. Since the scheduling within the cell is centrally controlled, the conventional DiL communication takes place sequentially (see Figure 1a), which means only one couple is transmitting at a certain time and thus the distance d_{AB} has no influence on the C/N.

However, for a fair comparison of DiL and SDiL, the offered data-rate instead of the signal quality should be regarded. With the help of Figure 4, it is possible to map the respective C/N, C(I+N) to an offered user data-rate. Keeping in mind, that conventional DiL scheduling offers only half the time of a MAC frame to each communicating couple, the achievable data-rate for DiL needs to be halved, whereas within SDiL *each* couple may use the whole disposable time. Considering this means, the reception quality in SDiL does not need to map the one in DiL in order to realise the same system throughput. As shown in Figure 4, for a reception quality of C/I, C/(I+N) = 18,2 dB half of the possible maximum throughput (43,5/2 = 21,75 Mbit/s) can be achieved. For higher values, the SDiL throughput always outperforms the one of DiL since SDiL allows concurrent communication and hence offers twice the capacity for the same C/I, C/(I+N) compared to the direct link! However, this does not necessarily mean that for smaller values of C/I, C/(I+N) the DiL performs better than the SDiL.

Beyond this background, one conclusion for both results in Figure 5 and Figure 6 is, that for the here shown reception quality (C/I, C/(I+N) > 20 dB) SDiL is always superior to conventional DiL scheduling. The reason for this is, that DiL is not able to further benefit from good link conditions, C/N, beyond approximately 32dB since the resulting throughput converges an upper limit of 43,5 Mbit/s. SDiL instead benefits from good conditions, C/(I+N), performs the parallel resource assignment and hence does not waste capacity.

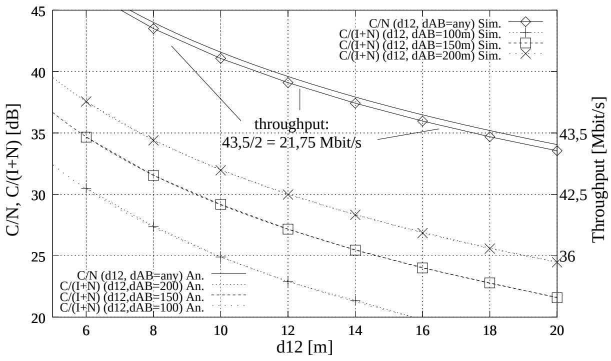

Figure 5: Signal quality for DiL (C/N) and SDiL (C/(I+N)) as a function of the terminal distance d_{12}

Shortly spoken one could say, that SDiL allows for a further exploitation of the radio resource since a respective high signal quality can directly be mapped to an increased throughput, whereas DiL is already working in saturation and thus cannot further benefit from an extraordinary reception quality. The achievable SDiL throughput for three selected receive power budgets (25, 30 and 35 dB), cp. Figure 4, is also included at the right side of Figure 5 and Figure 6. Please note, that the shown scaling is not linear.

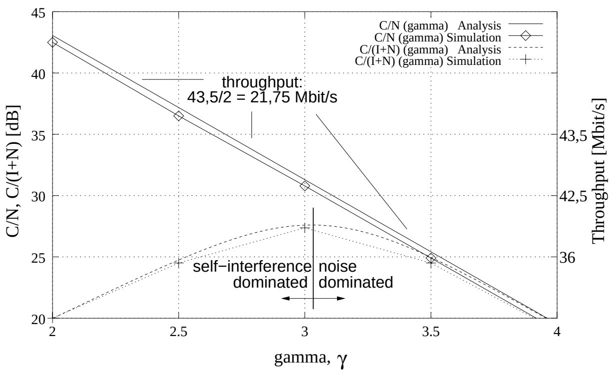

Figure 6: Impact of the propagation coefficient γ on the signal quality for DiL (C/N) and SDiL (C/(I+N))

In Figure 6 the impact of the propagation coefficient γ on the receive power budget is shown. The C/N curve for the conventional DiL approach shows a steady decreasing characteristic. The curve for the SDiL scheduling instead may be separated into two parts. Above a γ value of approximately 3, the attenuation along the signal path is that strong, that almost no interference due to the parallel transmission occurs. As a consequence, the two curves for DiL and SDiL approximate and only background noise is responsible for possible impacts on the reception quality (noise dominated). However, one should keep in mind that SDiL offers twice the data-rate of the DiL scheduling for those operation points! For γ values below 3 another interesting effect occurs: Contrary to the conventional DiL, the C/(I+N) shows an decreasing character for decreasing values of γ. The reason for this lies in the inherent self-interference of the parallel SDiL scheduling. For low attenuation values, the parallel scheduled second transmission thus shows a not negligible impact (self-interference dominated). As a consequence this does also mean, that the current signal quality for SDiL cannot be improved by simply increasing the transmission power. Nevertheless, as said for the investigations in Figure 5, the throughput for SDiL within this scenario is also always higher than for the DiL approach. Contrary to the investigations before, now there is an optimal point of operation with respect to a specific γ value. For real scenarios this means that there are certain environments that particularly benefit from SDiL appliance.

IV. Conclusions

Within this paper a new scheduling approach for resource grant in centralised controlled radio cells was introduced. The novel step lies in the parallel assignment of the same radio resource to enable 'smart' direct link communication between MTs, by which a more efficient usage of the spectrum is expected. For this, the respective interference situation at each MT needs to be considered. The appliance of smart direct link scheduling is possible if directly communicating MTs are spatially separated from other directly communicating MTs such that the same resource can be explored without mutual disturbance. The decision about the multiple assignment of same resources is performed by a central instance based on location- and interference distribution information. This information needs to be determined beforehand and administered inside the CC. For the here investigated scenarios, analysis and simulations performed for H/2 noted a remarkable gain in terms of throughput if the new, standard conform SDiL scheme is applied

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