Interference Protection versus Spatial Reuse in Wireless Networks

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Abstract—In this paper the capacity of decentralized wireless networks is addressed. An exclusion region is introduced that protects active receivers from destructive interference of nearby transmitters. An exclusion region imposes an upper bound on the interference that a transmitter may cause to receivers of competing links. While an exclusion region avoids excessive interference and thus improves capacity per link, the spatial reuse in terms of concurrently served links is compromised. The resulting trade-off is elaborated by computer simulations, so to optimize the exclusion range as a function of the user density and maximum transmit power. We demonstrate that by an appropriately specified exclusion range, the network capacity is substantially enhanced. In this context, it has been found that the exclusion range that maximizes the system capacity does not vary greatly when changing the a priori user density. In addition, the trade-off between maximizing the system capacity and maintaining fairness is investigated.

Index Terms—Network capacity, interference temperature constraint, decentralized interference management, receiver feedback, multiple access.

I. INTRODUCTION

Current wireless communication systems are restricted to specific spectrum bands. While some of the spectrum bands (such as mobile communication systems) are becoming overcrowded, other bands are notoriously underutilized. Cognitive radio [1], where spectrally agile users dynamically share the complete spectrum resource, has been identified as the enabler for a more efficient utilization of spectrum.

A fundamental prerequisite for meaningful spectrum sharing is the coexistence among spectrally agile users [2, 3]. Coexistence requires users to anticipate interference levels at the receiving end of competing links, so to satisfy a given interference temperature constraint (ITC) [2], which represents the limit on the maximum interference that may be induced to any active receiver. In wireless ad hoc networks an ITC is approximated by establishing an exclusion region around an active receiver, wherein transmitters of competing links must remain silent [4], as illustrated in Fig. 1. While the ITC imposes a limit on the aggregate amount of interference radiated to an active receiver, an exclusion range only limits the interference within the exclusion region. Unlike the ITC, the exclusion region can be readily implemented in practice by receiver feedback. As often the total interference tends to be dominated by a small number of interferers, the mismatch to the ITC is typically contained within reasonable limits. Various approaches to statistically quantify the interference in the exclusion region setting are presented in [5].

Receiver feedback is a common means for decentralized interference mitigation: transmitters that sense a strong feedback signal are denied access to a given resource unit (slot). Therefore, receivers are no more hidden from potential interferers. The feedback signal establishes an exclusion region around an active receiver, which effectively avoids the most detrimental interference caused by nearby transmitters [4]. Applications include medium access control based on RTS/CTS (request to send, clear to send) handshaking [6, 7] and busy-tone protocols, where out-of-band busy tones [8, 9] and in-band busy bursts [10–12] are distinguished. In-band receiver feedback utilizing time-multiplexed busy bursts [11, 12] possesses the appealing property that channel reciprocity can be exploited to impose an exclusion range: the strength of the observed feedback signal is equivalent to the potential interference this transmitter causes to an active receiver (transmitter of the busy burst) of a competing link. This effectively enables receivers to adjust the size of the exclusion region by tuning the maximum tolerable interference (MTI) level for which transmitters are still allowed to access a given slot. Besides interference mitigation, receiver feedback is also mandatory when maximizing the spectral efficiency of the own link by means of link adaptation [13–15].

By tuning the size of the exclusion region around active receivers, the optimum level of interference protection that maximizes the system capacity can be established. Assuming perfect link adaptation at the intended link, tuning the MTI is tightly coupled with the achieved system capacity. Increasing the MTI enhances the spatial reuse, so that more links can be served concurrently per unit area, whereas the capacity per link deteriorates due to increased interference. The resulting trade-off is elaborated by computer simulations. We demonstrate that an appropriately chosen MTI achieves superior system capacity, as well as a fairer distribution of resources among users, compared to greedy resource allocation with full spatial reuse of all resources where interference protection is omitted.

The remainder of this paper is organized as follows: for a wireless ad hoc network model introduced in Section II, interference protection by establishing an exclusion range
around active receivers and the corresponding MTI level is detailed in Section III, while the practical implementation of an MTI constraint by means of receiver feedback is addressed in Section IV. The appropriate adjustment of the exclusion range that maximizes the system capacity for an ad hoc network specified in Section V is examined in Section VI.

II. SYSTEM MODEL

A wireless ad hoc network is considered where \(N\) transmitters and \(N\) receivers are uniformly distributed, forming \(N\) communication links. Given the a priori link density \(\delta\), there are an average of \(E\{N\} = \delta A\) links distributed in area \(A\). The system bandwidth \(B\) and the transmission time \(T\) are divided into \(S\) transmission slots, \(BT = S B_s T_s\), where \(B_s\) and \(T_s\) denote the bandwidth and time occupied by one slot. This resembles a slotted medium access scheme, where resources are divided in time (time division multiple access (TDMA)) and/or frequency (orthogonal frequency division multiple access (OFDMA)). The slot allocation procedure determines \(N_{\text{act}} \leq N\) active links, which exchange data over a given slot, composed of the set of active transmitters \(T\) and receivers \(R\), so that the MTI for all active receivers is maintained. The slot allocation is modeled as an i.i.d. (independent and identically distributed) process with respect to the slot index. This implies that \(T\) and \(R\) changes from slot to slot, so that all \(N\) links are being served with non-zero probability. All transmitters use the same transmit power per slot \(E_s\), and perfect slot synchronization is assumed.

A. Channel Model

Distance dependent path loss and log-normal shadowing is assumed. The channel gain between transmitter \(Tx_x\) and receiver \(Rx_y\) is given by

\[
G_{xy} = c d_{xy}^{-\chi_{xy}} \exp(-\beta \epsilon_{xy})
\]  

where \(\beta = \ln(10)/10\) and \(d_{xy} > d_{\text{min}}\) denotes the distance normalized by the far-field reference distance \(d_{\text{min}}\). Furthermore, \(\chi_{xy}\) is the propagation path loss exponent, \(c\) is a constant path loss parameter, and \(\epsilon_{xy}\) is a zero mean, normal distributed random variable of shadow fading with standard deviation \(\sigma_{xy}\).

B. Interference Scenario

Consider an interference scenario where transmitter \(Tx_x\) has established a connection with receiver \(Rx_y\), as illustrated in Fig. 1. The interference \(Rx_y\) suffers from transmission of a competing link \(z\) is given by \(I_{zy}^d = G_{zy} E_s\). The aggregate interference at receiver \(Rx_y\) amounts to

\[
I_y = \sum_{z \in T, z \neq x} I_{zy}^d = \sum_{z \in T, z \neq x} E_s G_{zy}.
\]

This gives the signal to interference plus noise ratio (SINR):

\[
\gamma_y = \frac{E_s G_{xy}}{I_y + \eta}
\]

where \(\eta = k_B B_s \theta_0\) accounts for thermal noise, \(k_B\) is the Boltzmann constant, and \(\theta_0\) is the ambient temperature in degrees Kelvin.

C. Link and System Spectral Efficiency

Assuming that receiver \(Rx_y\) treats interference as noise, the (normalized) capacity of the link between \(Tx_x\) and \(Rx_y\) is given by the Shannon bound

\[
C_y = \log_2 \left(1 + \gamma_y\right), \quad y \in R, \quad \text{[bit/s/Hz]}.
\]

Then the system capacity per unit area amounts to

\[
C_{\text{sys}} = \frac{1}{A} \sum_{y \in R} C_y, \quad \text{[bit/s/Hz/km²]}.
\]

III. EXCLUSION RANGE AROUND ACTIVE RECEIVERS

Slot allocation is controlled by the access policy. To protect active receivers from excessive interference, an exclusion range around active receivers is introduced in [4]: a transmitter \(Tx_z\) is granted access to a given slot, if the potential interference \(I_{zy}^d\) induced at active receivers \(y \in R\), is below a predefined maximum tolerable interference (MTI)

\[
I_{zy}^d \leq I_{\text{th}}
\]

The MTI threshold \(I_{\text{th}} = v_{\text{max}} k_B B_s\) is a system wide constant, that corresponds to a maximum interference temperature \(\theta_{\text{max}}\) in degrees Kelvin, known within the entire network.

A. Effective Protection Radius

The MTI threshold (6) results in a protection radius around receiver \(Rx_y\), as illustrated in Fig. 1. In order to quantify the effective protection radius that accounts for shadowing, it is convenient to define an equivalent distance \(r_{xy}\) between transmitter \(Tx_x\) and receiver \(Rx_y\):

\[
r_{xy} = \frac{c}{G_{xy}}^{1/\chi_{xy}} = d_{xy} \exp \left(\frac{\beta \epsilon_{xy}}{\chi_{xy}}\right).
\]

The protection radius \(r_p\) is defined as the equivalent distance \(r_{xy}\) when the link gain \(G_{xy}\) in (7) approaches the interference threshold \(I_{\text{th}}/E_s\), which gives

\[
r_p = \left(\frac{c E_s}{I_{\text{th}}}ight)^{1/\chi_{xy}}
\]

Due to shadowing, the exclusion region is generally not a disk, as \(r_p\) varies with the location of the interferer.
### B. Active User Density & Spatial Reuse

The active user density represents the amount of concurrently served links per area $A$. Given uniformly distributed transmitters and receivers the active user density becomes

$$\delta_{\text{act}} = \frac{E\{ N_{\text{act}} \}}{A}. \quad (9)$$

The spatial reuse is a convenient measure for the amount of concurrently used links in the network. The spatial reuse factor is defined by the ratio between the a priori and active link densities

$$\varrho_s = \frac{E\{ N_{\text{act}} \}}{E\{ N \}} = \frac{\delta_{\text{act}}}{\delta}. \quad (10)$$

A spatial reuse factor of $\varrho_s = V$ means that on average $V\%$ of all links are active per slot. In case of full spatial reuse, $\varrho_s = 1$, all links are active, while for $\varrho_s \rightarrow 0$ only one link is active per slot within an unbounded network ($A \rightarrow \infty$). In the considered slotted medium access scheme with $S$ slots, $\varrho_s$ is also a normalized measure of the number of slots accessed by one link, provided that the outcome of the slot allocation procedure is independent of the slot index. Hence, any link, on average, is assigned $S \cdot \varrho_s$ slots.

#### C. Objective

The system capacity $C_{\text{sys}}$ in (5) depends on the interference threshold $I_{\text{th}}$ in (6). Lowering $I_{\text{th}}$ results in an enlarged protection radius $r_p$, which increases the SINR at receiver $R_{xy}$ and therefore improves the link capacity $C_y$. On the other hand, lower thresholds, on the other hand, are often needed, which reduces number of active links $N_{\text{act}}$ served in a given slot, so that the spatial reuse $\varrho_s$ in (10) is compromised. The interference threshold $I_{\text{th}}$ is therefore an important optimization parameter to maximize $C_{\text{sys}}$. The average system capacity is related to the active capacity $E\{ C_y \}$ as follows

$$E\{ C_{\text{sys}} \} = \delta_{\text{act}} E\{ C_y \} \quad (11)$$

where the expectation is taken over the set of receivers and network realizations.

The active link capacity $C_y$ as given in (4) is monotonically increasing with the effective protection radius $r_p$ in (8). In turn, however, less slots are available per link, as the spatial reuse reduces accordingly. It is therefore meaningful to define an effective link capacity $C_{\text{lk}}$, which also takes into account the allocated bandwidth per link. Suppose receiver $R_{xy}$ is served $s_y$ out of $S$ slots, then the effective link capacity amounts to $C_{\text{lk}} = C_y s_y/S$. Assuming that the slot allocation process is independent of the slot index, one link on average is served $E\{ s_y \} = S \cdot \varrho_s$ slots. The mean of the effective link capacity is therefore scaled by the spatial reuse factor $\varrho_s$ in (10), that is

$$E\{ C_{\text{lk}} \} = E\{ C_y \} \cdot \varrho_s = \frac{1}{\delta} E\{ C_{\text{sys}} \}. \quad (12)$$

Clearly, when no interference protection is in place, $r_p = 0$ then $\varrho_s = 1$, and therefore $C_{\text{lk}} = C_y$.

Apart from the system capacity $C_{\text{sys}}$, also a fair distribution of resources among competing links is an important figure of merit. To this end, $C_{\text{sys}}$ may be maximized by preferring links with high channel gains $G_{xy}$, while users with less favourable channel conditions starve for resources. As active receivers benefit from enhanced SINR as $r_p$ increases, enforcing an exclusion range around active receivers particularly benefits links with relatively poor channel gains $G_{xy}$, and therefore improves fairness. Fairness is quantified by the low percentiles of the cumulative distribution functions (cdf) of the effective link capacity $C_{\text{lk}}$, and the outage probability, expressed by the probability that $C_{\text{lk}}$ is below a minimum capacity $C_{\min}$, given by $Pr\{ C_{\text{lk}} < C_{\min} \}$.

We note that the objective of this work is not to find an optimized selection of active links (sets $T$ and $R$) that maximize $C_{\text{sys}}$. Rather we wish to find the optimum $I_{\text{th}}$ that maximizes $C_{\text{sys}}$ for a slot allocation policy (SAP) that results in arbitrary combinations of active links that satisfy (6). Furthermore, for the considered SAP it is assumed that idle slots are accessed immediately, i.e. transmitters instantly recognize that an MTI constraint (6) is satisfied. This is optimistic in the way that slot vacation times and collisions are ignored. On the other hand, the SAP performance is conservative in the way that the combination of active links is not subject to optimization.

#### IV. Busy Burst Protocol

For a communication link to attain its link capacity, a feedback link between receiver $R_{xy}$ and transmitter $T_x$ is required. Provided time-division duplex (TDD), comprising a time multiplexed data and low-rate feedback slot, an exclusion range around active receivers is effectively established by means of the busy burst protocol, for TDMA [11] as well as for OFDMA [12].

Let the measured signal power of the feedback link at $T_x$ be denoted by $I_{yb}^{\text{fb}} = G_{yz} E_x$. Provided channel reciprocity holds, i.e. $G_{zy} = G_{yz}$, the interference $I_{\text{zy}}^{\text{fb}} = G_{zy} E_x$ that $T_x$ imposes to $R_{xy}$, is equivalent to $R_{xy}$’s feedback measured at $T_x$, that is $I_{yb}^{\text{fb}} = I_{\text{zy}}$. A feedback signal from an active receiver $y \in R$, is detected as strong if the following condition holds

$$\max_{y \in R} I_{yb}^{\text{fb}} > I_{\text{th}}, \quad (13)$$

Hence, excessive interference at active receivers $I_{\text{zy}}$ is mitigated by restricting potential transmitters of competing links $z \neq x$ access to a given slot if (13) is met. Provided that transmitters follow (13), the MTI constraint (6) is maintained, i.e. a protection radius around active receivers $y \in R$ is established. The busy burst protocol is summarized as follows [11, 12]:

- Given successful reception of a slot and that transmitter $T_x$ has more data to transmit, receiver $R_{xy}$ emits a busy burst in a time-multiplexed mini-slot.
- If transmitter $T_x$, $z \neq x$ senses a strong busy burst (13), the slot is occupied, so that $T_x$ needs to reschedule its transmission to another slot.

In many cases $I_{yb}^{\text{fb}}$ is detected as an energy signal, in which case $T_x$ observes the aggregate $\sum_{y \in R} I_{yb}^{\text{fb}}$, so that...
Then the left hand side of (14) implies that the protection radius around receiver Rx_y increases as the number of active receivers |R| increases. This increased protection radius has the appealing property that in case of high network load where |R| tends to be large, inevitably causing more interference, Rx_y enjoys enhanced interference protection. For ease of analysis, however, we assume that \( \max_{y \in R} I^h_{yz} \) is available at Tx_z, resulting in a protection radius that is independent of |R|.

V. NETWORK GENERATION & ACTIVE LINK SELECTION

For performance analysis an ad hoc network is generated covering an area of \( A=1 \text{ km}^2 \) with a (system-wide) interference protection radius \( r_P \) in (8) around each active receiver. Monte Carlo simulations are conducted to compute the system and link capacities averaged over 1000 randomly generated networks. To eliminate border effects\(^1\), an enlarged network with area \( A>>A \) is generated, while results are only taken from receivers located within the central area \( A \) of the enlarged network. Given an a priori link density of \( \delta \text{ links}/\text{km}^2 \), the network is generated as follows:

1) \( \tilde{N} = \delta A \) transmitters are uniformly distributed in \( A=1.5 \times 1.5 \text{ km}^2 \) to form the enlarged network.
2) Associated to each transmitter a receiver is uniformly placed such that a maximum distance\(^2\) of \( d_{\max}=40 \text{ m} \) is not exceeded.
3) Receivers within the center area \( A=1 \times 1 \text{ km}^2 \) are marked for the generation of the performance metrics.

This generates a network with uniformly distributed transmitters. However, due to the maximum distance \( d_{\max} \) constraint, the distribution of receiving nodes does in general not follow a uniform distribution.

A set of active transmitters \( T \) and receivers \( R \) are to be selected such that the MTI constraint (6) is satisfied. This means that links are to be selected such that no active transmitter lies within the exclusion range of an active receiver of a competing link. To model the slot allocation procedure described in Section II, a bottom-up construction method is chosen, which functions as follows:

1) Originally all links are turned “off”, i.e. \( T=R=\emptyset \).
2) A randomly picked link \( (x,y) \) is activated (i.e. turned “on”) if transmitter Tx_x does not lie inside any exclusion range of neighboring active receivers, \( \text{and} \) the exclusion range of associated receiver Rx_y does not cover any transmitter of neighboring links that is already turned “on”.

\(^1\)In a network of finite size, receivers near the borders are surrounded by interferers from only 2 or 3 sides, and therefore are exposed to less interference compared to receivers in the center area of the network.

\(^2\)The maximum distance of \( d_{\max}=40 \text{ m} \) is obtained such that for transmit powers \( P_s \geq 0.4 \text{ mW} \) an average SNR>0 dB (signal to noise ratio excluding interference) is maintained.

Fig. 2. Example for a randomly generated ad hoc network with active link selection. For illustration purpose an arbitrary \( 100 \times 100 \text{ m}^2 \) network is displayed, with 20 links with maximum distance of \( d_{\max}=40 \text{ m} \). Solid and dashed lines denote active and inactive links, respectively. Transmitters are marked as filled nodes, and receivers as empty nodes. The mean of the exclusion radii, \( d_P=E(r_P)=10 \text{ m} \), are drawn as circles around active receivers.

3) Step 2 is repeated for all links.
In this way, all active transmitters are outside the exclusion ranges of active receivers of neighboring links. Fig. 2 shows an example of a randomly generated ad hoc network.

VI. PERFORMANCE EVALUATION

An indoor non-line-of-sight path loss model with log-normal shadowing is assumed, specified by the IST-WINNER project [16]. The associated channel gain (1) in dB is given by

\[
G_{xy} = -36.8 \log_{10}(d_{xy}) - 38.8 - \epsilon_{xy} \quad [\text{dB}]
\]  

The channel model (15) is derived from (1) by setting the path loss exponent, the constant path loss parameter, and the log-normal shadowing standard deviation to \( \chi_{xy}=3.68 \), \( c = 1.32 \times 10^{-4} \), and \( \sigma_{xy} = 3.5 \text{ dB} \), respectively [16]. Room temperature of \( \vartheta_0 = 300 \text{ K} \) and a bandwidth of \( B=15 \text{ MHz} \) are assumed, which yield the thermal noise \( \varpi \approx -132 \text{ dBW} \).

In Fig. 3 a network with an a priori density of \( \delta = 300 \text{ links}/\text{km}^2 \) and a transmit power of \( E_s=50 \text{ mW} \) is analyzed as a function of the average protection radius \( d_P = E(r_P) \) in meters. Also shown is the spatial reuse factor \( \vartheta \) defined in (10), along with the average active link capacity \( E(C_d) \).

It is seen that the active link capacity and the spatial reuse are monotonically increasing respectively decreasing functions of \( d_P \). This can be attributed to the fact that increasing \( d_P \) allows for less links, which means less interferers who tend to be located further away from active receivers. Hence the SINR and in turn the link capacity increase. The results show that an optimum for \( d_P \) exists that...
maximizes the system capacity $E\{C_{\text{sys}}\}$. For $E_s=50$ mW this optimum lies at $d_{P,\text{opt}}=40$ m, corresponding to an interference threshold of $I_{th}=-67.8$ dBm. The optimum protection radius $d_{P,\text{opt}}=40$ m offers a gain of 25% in capacity over a system without interference protection ($d_P=0$ m). Removing transmitters in close vicinity to active receivers, proves to be beneficial in terms of system capacity, as destructive interference is avoided. Further increasing $d_P$ results in a loss in system capacity exceeding 50% for $d_P=120$ m. Now the loss in spatial reuse by dropping links outweighs the boost in SINR. This behaviour is related to the fact that the number of active links contributes linearly to $C_{\text{sys}}$, while an increase in SINR $\gamma$ only logarithmically increases $C_{\text{sys}}$, in case $\gamma \gg 1$.

Fig. 4 shows the cdf of the effective link capacity $C_{lk}$ for some protection radii $d_P$. The effective link capacity $C_{lk} = C_y s_y/S$, where $s_y$ denotes the number of served slots to receiver $\text{Rx}_y$, takes into account that only a portion of the total bandwidth $B$ is available per link (see Section III-C), and therefore accounts for the reduced spatial reuse with growing protection radius $d_P$. Allowing for an exclusion range $d_P>0$ around active receivers greatly improves $C_{lk}$ at the low percentiles of the cdf. This is a clear indication that a growing $d_P$ facilitates a fair distribution of resources to all links: users with comparably poor link quality (low percentiles of the cdf) particularly benefit as $d_P$ increases, at the expense of the users with superior link quality (high percentiles of the cdf). The outage probability $P\{C_{lk} \leq C_{\text{min}}\}$, with a minimum capacity set to $C_{\text{min}}=0.1$ bits/s/Hz, tremendously improves for enlarged $d_P$. For a system with $d_P=0$ m, where all links are active in each slot, the outage probability exceeds 50%. On the other hand, for $d_P=100$ m, outage diminishes; however, the system capacity (see Fig. 3) suffers distinctively. Contrary to this, $d_{P,\text{opt}}=40$ m maximizes the system capacity, at the expense of an outage probability of $\approx 8\%$. Hence by setting an MTI constraint, system capacity can be traded with fairness. For instance, a maximum outage of 5% is achieved by a protection radius of $d_P=60$ m, which still yields 97% of the maximum system capacity (see Fig. 3).

In Fig. 5 the link and system capacities are plotted against the protection radius $d_P$. For a constant transmit power of
radius stays within an appropriately dimensioned maximum tolerable interference, the optimum exclusion range that maximizes system capacity hardly changes for a wide range of user densities. This is an encouraging observation, especially for highly dynamic networks, as it allows to specify one common exclusion range that is applicable to different deployment scenarios, without sacrificing system capacity. Furthermore, the trade-off between maximizing the system capacity and maintaining fairness was elaborated. Increasing the exclusion range beyond the operating point that maximizes system capacity favours users with relatively poor channel gains, and thus achieves a more fair distribution of resources to all links.

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**Fig. 6.** Varying transmit power $E_s$. The mean of the system capacity $E\{C_{sys}\}$ is displayed as a function of the average protection radius $d_p$. Results are shown for five different transmit powers, $E_s=0.5, 2.5, 5, 25,$ and $50$ mW.

$$E_s=50 \text{ mW}, \text{the link density is increased from } \delta = 500 \text{ links/km}^2 \text{ to } 500 \text{ links/km}^2. \text{ As } \delta \text{ augments links are added, and so are interferers.} \text{ More links enhance the system capacity } E\{C_{sys}\}, \text{ while more interferers degrade the link capacity } E\{C_{ly}\}, \text{ a trend that is in line with the asymptotical bounds reported in } [17]. \text{ The attainable gains in system and link capacity with an appropriately chosen } d_p \text{ grow with increasing link density } \delta. \text{ This means that the more interferers exist in the network, the more beneficial interference protection of active receivers becomes.} \text{ Interestingly, the optimum protection radius stays within } 40 \text{ m} \leq d_{p, opt} \leq 50 \text{ m} \text{ over a wide range of user densities } \delta. \text{ Hence, for arbitrary networks with a fixed transmit power, a fixed and pre-defined exclusion radius } d_p \text{ can be specified, independent of the number of users.} \text{ Fig. 6 shows the system capacity } E\{C_{sys}\} \text{ as a function of the protection radius } d_p \text{ for varying transmit powers } E_s. \text{ The } a \text{ priori link density is set to } \delta = 300 \text{ links/km}^2. \text{ Increasing } E_s, \text{ while keeping the } a \text{ priori link densities } \delta \text{ constant, raises the observed interference at each receiver.} \text{ The system then becomes interference limited, i.e. the noise part of the SINR is marginalized so that SINR } \rightarrow \text{SIR, which results in an enhanced system capacity for all } d_p, \text{ a trend which is also confirmed by the analysis in } [18]. \text{ Moreover, Fig. 6 reveals that } d_{p, opt} \text{ grows with increased } E_s, \text{ which indicates that the MTI constraint plays a more significant role.} \text{ Due to the increase in } E_s, \text{ the link capacity grows, provided that the interference is kept low, which favours an increased } d_{p, opt}. \text{ VII. CONCLUSIONS} \text{ In this paper, decentralized interference management based on in-band receiver feedback was investigated. An active receiver is given an exclusion range where transmissions of neighboring links are not allowed to transmit. While the provision of an exclusion range boosts the SINR, the spatial reuse is compromised, in terms of concurrently transmitting links per unit area. By tuning the size of the exclusion range by an appropriately dimensioned maximum tolerable interference, significant gains in system capacity are observed. Interestingly, the optimum exclusion range that maximizes system capacity hardly changes for a wide range of user densities. This is an encouraging observation, especially for highly dynamic networks, as it allows to specify one common exclusion range that is applicable to different deployment scenarios, without sacrificing system capacity. Furthermore, the trade-off between maximizing the system capacity and maintaining fairness was elaborated. Increasing the exclusion range beyond the operating point that maximizes system capacity favours users with relatively poor channel gains, and thus achieves a more fair distribution of resources to all links.}