A Novel Approach for Back-haul Self Healing in 4G/5G HetNets

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***Abstract*—4G/5G Heterogeneous Networks (HetNets), which are expected to have a very dense multi-layer network structure, have emerged as a solution to satisfy the increasing demand for high data rates. These networks, similar to other networks, are subject to failures of communication components, which may occur due to many reasons. Self-Healing (SH) is the ability of the network to continue its normal operation in the presence of failures. The contribution of this paper is to introduce a novel SH approach for all network base-stations (BSs) back-hauling in a HetNet. New SH radios are proposed with enabled Cognitive Radio (CR) capabilities for utilizing the spectrum. A Software Defined Wireless Network Controller (SDWNC) is used to handle all control information between all network elements (except user equipment). This novel pre-planned reactive SH approach ensures network reliability under multiple failures. A simulation study is conducted to assess the performance of our approach through the evaluation of the Degree of Recovery (DoR) under single and multiple failures. Our approach can achieve a DoR of at least 10% using only 1 SHR and an enhanced DoR can be achieved using a greater number of SHRs.**

***Index Terms*—Self Organizing Network (SON), Self-Healing (SH), Heterogeneous Networks (HetNets), 4G, 5G.**

I. INTRODUCTION

A wide range of data rates has to be supported in 4G/5G networks, which can be as high as multiple gigabits per second per user, and tens of megabits per second need to be guaranteed with very high availability and reliability in the presence of failures [1].

Wireless cellular systems, as most other systems, are prone to failures. The failures can be classified as software or hardware failures. Software failures can be mitigated automatically by restarting or reloading the failed node software while most hardware failures have to be manually repaired through a cell site visit which may take a few hours (up to 24 hours) for repair. During the repair time, the network must operate near normal conditions with acceptable quality of experience [2].

A Self Organizing Network (SON) aims to leapfrog to a higher level of automated operation (minimize human interaction) in wireless networks by self managing the planning, configuration, optimization and healing of networks. Networks implemented according to 3GPP specifications will take advantage of this enhancement in wireless networks [3]. SONs can be implemented in different architectures including distributed, centralized and hybrid.

Future cellular networks, which provide high speed data rates with high reliability, are prone to all types of failure; internal and external, and software and hardware. This is why Self-Healing (SH) must be provisioned. Our proposed SH approach aims to mitigate back-haul failures, which are categorized as external failures, for all network BSs with high reliability and a minimum guaranteed data rate.

We propose to add this scheme to the upcoming 4G releases or the upcoming 5G standard to adapt the new hardware modifications to the network BSs. For 5G standard, our proposed scheme must be adapted to the new 5G channel models.

The remainder of this paper is organized as follows: Section II is the literature review of the previous work. In Section III, we explain the technical details of our proposed approach. In Section IV, the system architecture is described in detail. Section V introduces the three algorithms used in the SH process followed by the channel model in Section VI. Sections VII and VIII present the results and the conclusions, respectively.

II. LITERATURE REVIEW

SON is divided into three categories: self-configuration, self-optimization and self-healing. SON is a rapidly growing area of research and development, and in the last decade many research efforts have been exerted in this area.

Most work done in the SH field addressed the cell outage detection and cell outage compensation. Studies on cell outage detection focused on fault detection, classification and also on minimizing the failure detection time [2], [5]–[7]. In cell outage compensation, all neighbor cells cooperate to compensate the failure. The neighbor cells can compensate the failure by increasing the transmission power and/or changing the antenna tilt [8]–[10].

Many existing studies focused on macrocell SH, while a few of them have investigated the problem in the case of HetNets. In [9] the authors introduced a two tier macro-femto system and presented three different SH architectures. Then they proposed a local cooperative scheme for outage detection and compensation. They claimed that this scheme satisfies the practical requirements imposed by features of femtocells.

Future 4G/5G HetNets are characterized by very high speed connections so back-haul failure for a few minutes with gigabits per second speeds can cause the loss of hundreds of gigabits or even terabits. Despite the importance of back-haul SH in these networks, all recent work relates to the BSs SH, without addressing the problem of back-haul SH.

III. The Proposed System Model

In this paper, we consider an LTE HetNet consisting of one macrocell, which uses optical fiber link for its back-hauling, placed at the center of the coverage area and N_p picocells placed by the operator at certain spots based on the network planning. The picocells get their back-hauling directly from the macrocell using microwave connections. There are N_f femtocells which back-hauled by wired connections via internet service providers; some of the femtocells are placed by the operator and the others are placed by network users. Each of these BSs is equipped with a number of Self Healing Radios (SHRs) and they are connected logically, via TCP connection to a Software Defined Wireless Network Controller (SDWNC). The BSs use the concept of Cognitive Radio (CR) to share the spectrum of the network to be used by the SHRs.

A. Self-Healing Radios (SHRs)

SHRs are additional radios added to all network BSs which supply SH alternate connection(s) for the BS that suffers from back-haul failure. The number of SHRs in each type of BS is a design parameter and is studied below by simulation. These radios operate in the same frequency spectrum of the operator using the CR concept as discussed below. The maximum theoretical coverage range for the SHRs is assumed to be 100 meters. The SHRs used in macrocells are directional and serve the sectors in which they are located while those used in picocells and femtocells are omni-directional.

B. Software Defined Wireless Network Controller (SDWNC):

In the emerging Software Defined Networking (SDN) paradigm, the control plane and the forwarding plane are separated. Routers and switches implement the forwarding function only, and hence, they are simplified. However, the flow tables are populated by the control plane, which is implemented by the SDN controller(s). This approach has many advantages, including a global optimal routing function implementation, simplification of networking, enabling programmability and easy deployment of new functions and protocols.

Applying the SDN concept to wireless networks has been recently introduced in [11]. In this case, radio access networks, including WiFi access points and 3GPP EUTRAN, implement the access, forwarding and routing functions, and support multiple functionality levels at L2 and L3. These devices are controlled by a SDWNC which, in addition to controlling the flow tables, provides new functions. Among these functions, we propose to have the SDWNC control the BSs, e.g., macrocell, picocells, and femtocells, in order to implement the SH function proposed in this paper.

C. Cognitive Radio (CR) Concept

CR is a form of wireless communication spectrum access paradigm in which a transceiver of a secondary user can intelligently detect which communication channels are in use by their licensed, or primary users, and instantly tune to vacant channels. Once the primary user is detected to have become active, the secondary user vacates the channel [12].

In this paper, we develop a SH scheme that is based on the same concepts of CRNs, but in a slightly different way. The primary and the secondary users' roles are played by the same users, which are BSs. However, the primary users are the BSs involved in recovery from back-haul failures, and the frequency channels used for recovery are those channels allocated for recovery. At the same time, the secondary users are also BSs using those primary channels for normal operation, i.e. access channels, when there are no failures. Once there is a failure, the BSs switch roles (from secondary to primary users) and give up the use of those channels for normal operation, and start using them as (primary users) to recover from failures.

The use of the CR concept will lead to substantial improvements in overall spectrum utilization, where a portion of the access band will be reserved for the BSs to use as a primary user when operating in the SH mode (in case of failures). In the normal mode, this portion will be fully utilized where the BSs will use this band, but as secondary users. This results in operating SHRs without reserving a permanent portion of the spectrum (bad utilization) or adding to the CAPEX and OPEX by purchasing a new spectrum.

D. Femtocells used

There are two different types of femtocells which are categorized based on the femtocell owner.

1) Pre-planned Femtocells (PFs): These are owned and controlled by the network operator and they are deployed in large enterprises such as universities, malls, airports, and other public places.

2) Random deployed Femtocells (RFs): They are owned by network users and each user installs this femtocell in his home or small office, hence the deployment of this type of femtocells is totally random.

Network user is free to purchase a regular femtocell (which does not contain SHRs) or a SH femtocell (RF). In the latter case users are involved in the SH process and the operator must use some means of compensation or incentives for those users. The authors of [13] proposed some pricing schemes for users relaying data in D2D 5G networks. They proved that these compensation schemes bring significant gains for both the operator and the users compared to the single tier scenario.

IV. System Architecture

The architecture that we use to deploy our SH strategy in is shown in Fig.1 which is similar to the 4G architecture with a multi-layer heterogeneous hierarchical topology which consists of a marcocell, picocells, and femtocells and each one has its own wired or wireless back-hauling. There are two main differences between the 4G architecture and the architecture that we used: 1) All cells in this architecture can operate in normal operational mode and/or SH (mesh) mode, where the SH (mesh) mode will only be activated in case of failure and it will be activated in the failure region only to heal the network in this region. 2) Microcells are no longer used here. This is because 80% of traffic is used indoor by users and 20% only is used outdoors. Therefore the macrocell with the aid of a number of picocells deployed in dense areas will carry the 20% outdoor traffic and the wide deployment of picocells and femtocells will carry the 80% indoor traffic. Also this solution will increase the network capacity per Km^2 (bits/s/Km$^2/user$) which is one of the 5G objectives (see [14] for more details for deploying small cells in 5G networks) [9].

Fig.1 shows the architecture used to deploy our SH strategy which consists of one centered macrocell that serves the outdoor UEs and also provides back-haul connectivity to picocells through microwave links. All femtocells are back-hauled using wired connections. The SDWNC is connected to all network elements except the users equipment (UE).

The PFs are deployed by the operator as explained earlier and they have two functionalities; 1) They provide service to UEs, and 2) They provide SH connections for failed BSs. The operator must consider these two points when determining the PFs locations. We conjecture that three PFs in the SHRs range of the macrocell (one in each sector) and one PF in the SHR range of each picocell will be sufficient. SH consists of three steps: 1) detection, 2) analysis and 3) mitigation of failure.

In Fig.2, the normal operation of the network means that it is operating without any failures in any BS in the network. The system is monitored for detection of any failure by SDWNC. In the case of failure, the SH approach will be activated and it will be implemented in the failure region only and the rest of the network operates in the normal mode. When the failure is repaired, the normal operation mode is recovered again and the SH function will be deactivated. From the timing point of view, Fig. 2 shows that the normal operation can continue for hours or days without any failure or error interruption. In the case of failure, and with the help of SDWNC, the system will detect and activate the SH strategy within a few milliseconds. System repair, which is done by the operator maintenance personnel, can typically be done within 24 hours at most and in this case, our SH strategy will provide recovery that satisfies the minimum system requirements in the failure region. Switching back to normal operation is performed in multiple of milliseconds after system repair and is triggered by the SDWNC which will deactivate all SHRs for all BSs.

V. The Self-Healing Algorithms

We will now consider the different failure cases in wired and wireless back-hauling (regardless of whether it is one failure at a time or multiple failures) and demonstrate how the SH mode activation will provide connectivity during failure. All BSs back-haul failure will be considered under the following three categories:

A. Macrocell Back-haul Failure

Macrocell is the most important BS in the network because in addition to its main functionality (providing connectivity to outdoor users) it provides wireless back-hauling to other small cells (i.e., picocells). Macrocell back-haul failure means multiple failures at the same time which is the worst case when dealing with SH networks.

In Algorithm 1, the SDWNC in the first 3 lines checks the status of the macrocell back-hauling and if it is failed, it immediately activates the SHRs of all BSs in the failure region. Line 4 is the beginning of the SH procedures and this loop terminates only after repairing the back-haul failure of the macrocell. In lines 5-19, all picocells will search for a K alternate back-hauling BSs, where K is the number of SHRs. Each picocell will try to connect to the different BSs in the following order of precedence: PFs, RFs, and picocells. The picocells have the least priority because recovered picocell recovering another picocell is a second hop recovery which happens only if there are no PFs or RFs in the picocell SHRs range. From line 20 to 29, the macrocell searches for back-haul connections using its SHRs from PFs and RFs, respectively. Then it receives connectivity via microwave link from those picocells that are back-hauled directly from femtocells so that the total number of hops will be two which is the maximum in our model, as in lines 30-34. As shown in lines 35-40, the SDWNC disables the unused SHRs of all femtocells and then collects the status of all BSs in the region of the failed macrocell. This process is repeated until the failure is repaired. At this point the SDWNC deactivates all SHRs for all BSs.

Referring to Fig. 3, when the macrocell back-hauling fails, the SH process will be triggered by the SDWNC and suppose that the macrocell has 2 SHRs in each sector and also each picocell has 2 SHRs. Then Pico 1 will connect to PF 1 SHR first and then it will connect to RF 3 SHR where both are in Pico 1 SHRs range. The same will happen with Pico 2, which will connect to RF 2 and RF 8, and Pico 3 which will connect to PF 3 only because there is no RFs in range to connect to. The macrocell will be connected to all picocells via microwave connection and also will connect to PF 6, 7, 8 and RF 6.

B. Picocell Back-haul Failure

When the picocell microwave link fails, the macrocell will inform the SDWNC which will activate the SHRs of all BSs in the failed picocell region in order to begin the SH procedures as shown in Algorithm 2. From the beginning until line 3, the SDWNC detects the failure and activates the SHRs of all BSs. Line 4 is the beginning of the SH procedures and this loop terminates only after repairing the back-haul failure of the picocell. In lines 5-22, the picocell will try to connect to K alternate back-hauling BSs. It will try to connect to the different BSs in the following order of precedence: Macrocell, PFs, picocells, and RFs. The RFs have the least priority because they are not owned by the operator and the RF owner will have some sort of compensation from the operator when using his RF in the SH process. In lines 23-26, the SDWNC disables the unused SHRs of all femtocells and then collect the status of all BSs in the region of the failed macrocell. This process is repeated until the failure is repaired. At this point the SDWNC deactivate all SHRs for all BSs.

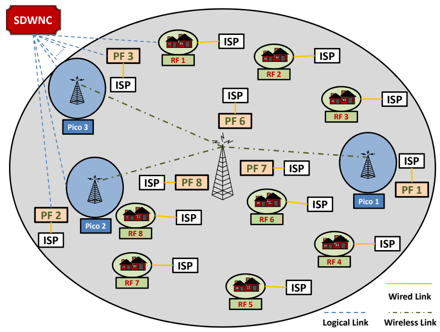

Fig. 1 : The network architecture.

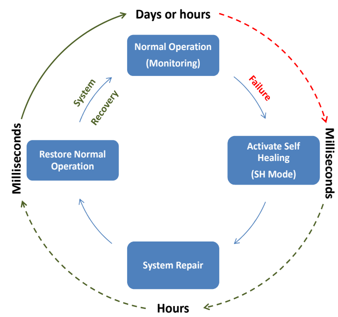

Fig. 2 : Self Healing activation procedures.

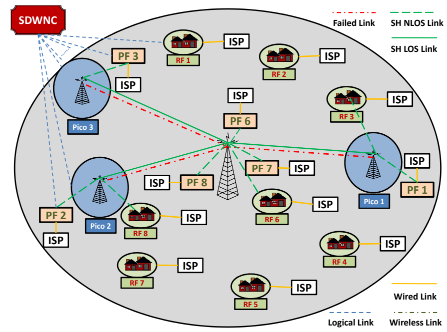

Fig. 3 : Macrocell Failure scenario.

Algorithm 1: Macrocell Back-haul Algorithm

```
Input: Macrocell back-hauling status, K (number of picocells
       SHRs), M (number of macrocell SHRs)
if Macrocell back-haull status is failed then
    SDWNC activates SHRs for all BSs
end
while Back-haul status is failed do
    for k ← 1 to N_p do
        Picocell measures RSS from PFs SHRs
        Picocell connects to N PFs SHRs (RSS> RSS_th)
        K=K-N (Picocell remaining unconnected SHRs)
        if K!=0 (not all picocell SHRs connected) then
            Picocell measures RSS from all RFs SHRs
            Picocell connects to L RFs SHRs (RSS> RSS_th)
            K=K-L (Picocell remaining unconnected SHRs)
        end
        if K!=0 (not all picocell SHRs connected) then
            Picocell measures RSS from all picocells SHRs
            Picocell connects to P picocells SHRs (RSS>
            RSS_th)
            K=K-P (Picocell remaining unconnected SHRs)
        end
    end
    for i ← 1 to 3 (for each macrocell sector) do
        Macrocell measures RSS from PFs SHRs
        Macrocell connects to Q PFs SHRs (RSS> RSS_th)
        K=K-Q (Macrocell remaining unconnected SHRs)
        if K!=0 (not all macrocell SHRs connected) then
            Macrocell measures RSS from all RFs SHRs
            Macrocell connects to R RFs SHRs (RSS>
            RSS_th)
            K=K-R (Macrocell remaining unconnected SHRs)
        end
    end
    for k ← 1 to N_p do
        if picocell is receiving 1 hop back-haul connectivity
        then
            Macrocell connects to picocell via microwave link
        end
    end
    for k ← 1 to N_f do
        if femtocell didn't receive back-haul request for 200 ms
        then
            SDWNC deactivates femtocell SHRs
        end
    end
    SDWNC collects the status of all BSs
end
SDWNC deactivates SHRs for all BSs
```

Algorithm 2: Picocell Back-haul Algorithm

```
Input: Picocell back-haul status, K (number of picocell SHRs)
if Picocell back-haul status is failed then
    SDWNC activates SHRs for all BSs
end
while Back-haul status is failed do
    Picocell measures RSS from macrocell SHRs
    Picocell connects to M macrocell SHRs (RSS> RSS_th)
    K=K-M (Picocell remaining unconnected SHRs)
    if K!=0 (not all picocell SHRs connected) then
        Picocell measures RSS from all PFs SHRs
        Picocell connects to N PFs' SHRs (RSS> RSS_th)
        K=K-N (Picocell remaining unconnected SHRs)
    end
    if K!=0 (not all picocell SHRs connected) then
        Picocell measures RSS from all picocells SHRs
        Picocell connects to P picocells SHRs (RSS> RSS_th)
        K=K-P (Picocell remaining unconnected SHRs)
    end
    if K!=0 (not all picocell SHRs connected) then
        Picocell measures RSS from all RFs SHRs
        Picocell connects to L RFs SHRs (RSS> RSS_th)
        K=K-L (Picocell remaining unconnected SHRs)
    end
    if other BSs didn't receive back-haul request for 200 ms
    then
        SDWNC deactivates these BSs SHRs
    end
    SDWNC collects the status of all BSs
end
SDWNC deactivates SHRs for all BSs
```

C. Femtocell Back-haul Failure

Similar to the picocell failure, when femtocell back-haul fails, the same picocell SH procedures will be used. In case of multiple failures, i.e., two or more femtocells back-hauls fail at the same time, the SDWNC will apply the femtocells SH algorithm for each failed femtocell.

VI. Pathloss and Channel Model

A. Pathloss Model

The pathloss here is considered between the network BSs communicating using the SHRs. We have 4 different pathloss models.

1) Outdoor to Outdoor Pathloss (O2O): This case happen when for example two picocells communicates using the SHRs. The pathloss equation is given by [15]

$$\mathrm{PL}_{O2O,\mathrm{dB}} = \kappa + \nu \log_{10} d_{O2O},$$

where d_{O2O} is the outdoor distance between the picocell and macrocell. Here κ and ν correspond to the pathloss constant and pathloss exponent, respectively.

2) Outdoor to Indoor Pathloss (O2I): This is the case when a macroell or a picocell communicates with a femtocell or vice versa. The pathloss equation is given by [15]

$$\begin{aligned}\mathrm{PL}_{O2I,\mathrm{dB}} =& max(38.46 + 20 \log_{10} d_{\mathrm{out}}, \kappa + \nu \log_{10} d_{\mathrm{out}}) \\ &+ 0.3 d_{\mathrm{in}} + q L_{\mathrm{iw}} + L_{\mathrm{ow}},\end{aligned}$$

where d_{out} is the distance traveled outdoor between the outdoor BS and the building external wall, d_{in} is the indoor traveled distance between the building external wall and femtocell, the maximum, in the first term, is to consider the worst case, the loss due to internal walls is modeled as a log-linear value equal to 0.3dB per meter, L_{iw} is the penetration loss of the building internal walls, q is the number of walls and L_{ow} is an outdoor-indoor penetration loss (loss incurred by the outdoor signal to penetrate the building).

3) Indoor to indoor Pathloss (I2I): This is the case when a femtocell communicates with another femtocell in the same building. The pathloss equation is given by [15]

$$\mathrm{PL}_{I2I,\mathrm{dB}} = 38.46 + 20 \log_{10} d_{in} + 0.3 d_{in} + q L_{\mathrm{iw}},$$

where d_{in} is the indoor distance between the two in-building femtocells. The first term $38.46 + 20 \log_{10} d_{in}$ is the distance dependent free space pathloss.

4) Indoor to Outdoor to Indoor Pathloss (I2O2I): This is the case when a femtocell communicates with another femtocell in a different building. In this case a new pathloss equation is proposed by modifying O2I equation, adding an additional outdoor-indoor penetration loss and considering the indoor distance in the two buildings. This is equivalent to dividing the total distance between the two femtocells into $(d_{in_1} + d_{out_1})$ and d_{in_2}. In this case considering $d_{in_1} = d_{in_2} = d_{in}$, $d_{out_1} = d_{out}$ and $L_{\mathrm{ow}_1} = L_{\mathrm{ow}_2} = L_{\mathrm{ow}}$. The pathloss equation is given by [15]

$$\begin{aligned}\mathrm{PL}_{I2O2I,\mathrm{dB}} =& max(38.46 + 20 \log_{10} d_{\mathrm{out}}, \kappa + \nu \log_{10} d_{\mathrm{out}}) \\ &+ 0.3(2 d_{\mathrm{in}}) + q L_{\mathrm{iw}} + 2 L_{\mathrm{ow}},\end{aligned}$$

B. Channel Model

Taking into account shadowing fluctuations in addition to the pathloss, the channel gain in dB between any two BSs can be expressed as [15]

$$h_{\mathrm{BS1,BS2,dB}} = -PL_{\mathrm{BS2,BS2,dB}} + \xi_{\mathrm{BS1,BS2}},$$

where the first factor captures propagation loss, according to the first 4 equations. The second factor, captures log-normal shadowing with zero-mean and a standard deviation $\xi_{\mathrm{BS1,BS2}}$.

VII. Results and discussion

A. Simulation Model

In the following evaluations we consider dynamic deployment scenarios in an urban area where an LTE coverage area is circular with radius 500 m, with a macrocell BS at the center. The number of picocells ($\mathrm{N_p}$) is 6, located as 2 in each macrocell sector. There are 9 PFs, 1 in each macrocell sector and 1 in the SHRs range of each picocell, and 50 RFs distributed randomly over the macrocell coverage area so that the total number of femtocells ($\mathrm{N_f}$) is 59. The simulation parameters are shown in table I.

B. Simulation Results

Extensive simulations for different failure scenarios have been conducted for the macrocell, picocells, and femtocells. The RF input rate is heterogeneous (20, 60, 100 Mbps) and is distributed between these RFs with ratios 50%, 40% and 10%, respectively in macrocell and picocells failure scenarios. But it is fixed to 100 Mbps in femtocell failure scenario to evaluate the results in the worst case.

TABLE I: Simulation Parameters

Parameter	Value	Parameter	Value
Microcell input rate	10 Gbps	SHRs max. power	15 dB
Picocell input rate	1 Gbps	κ	15.3 dB
PF input rate	200 Mbps	ν	37.6 dB
RF input rate	$20, 60, 100$ Mbps	L_{ow}	20 dB
System Bandwidth	20 MHz	L_{iw}	5 dB
RSS_{th}	-153 dB	$\xi_{\mathrm{BS1,BS2}}$	8 dB
Frequency band	2.6 Gbps	q	2 walls

We evaluate our SH approach in terms of Degree of Recovery (DoR) from failure. The DoR of a certain BS is defined, in terms of SH as:

$$DoR = \frac{Summation\ of\ recovered\ rates\ from\ other\ BSs}{Original\ input\ rate\ of\ the\ failed\ BS}$$

1) Macrocell Failure: As mentioned before, the macrocell failure is a special case. Therefore, we have one failure which implicitly causes multiple failures (all picocells back-hauled from macrocell will fail). Hence, the DoR of the macrocell is assessed with respect to the number of SHRs of the macrocell and the other picocells involved in the SH process.

As shown in Fig. 4 when increasing the number of macrocell SHRs, the DoR increases but not as much as when increasing the number of picocell SHRs. Using 1 picocell SHR and increasing macrocell SHRs from 1 to 4 can improve the DoR by 26%. However, using 1 macrocell SHR and increasing picocell SHRs from 1 to 4 can improve the DoR by 60%. This means that investing in picocell SHRs will enhance the SH performance than investing in macrocell SHRs. In the next two scenarios, the macrocell SHRs will be fixed to 3 SHRs.

2) Picocell Failure: Fig. 5 evaluates the DoR of picocell when increasing the picocell SHRs from 1 to 7 under single and multiple failure scenarios. In case of single failure, the DoR increases rapidly from 10% to 20% by increasing the SHRs from 1 to 4. Further increase in the SHRs results

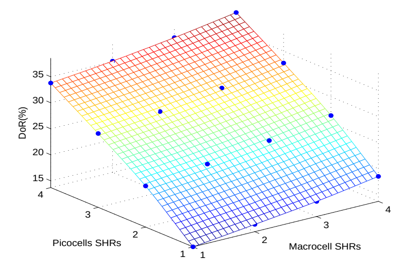

Fig. 4: DoR of macrocell vs. number of SHRs.

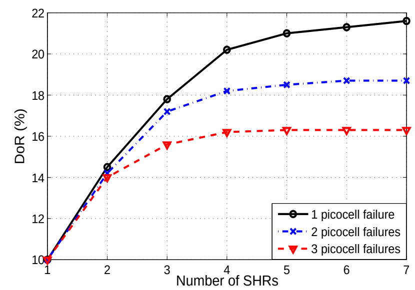

Fig. 5: DoR of picocells vs. number of SHRs.

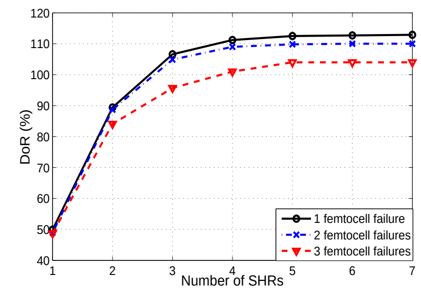

Fig. 6: DoR of femtocells vs. number of SHRs.

in negligible increase in the DoR which proves that the recommended number of SHRs to be used by picocells is 4.

Also we can see in Fig. 5 in the case of multiple failure that all failed picocells can recover their rates by 10% using 1 SHR. This is because, as mentioned before, each picocell has a dedicated PF in its SHRs range. Therefore, under multiple failures each failed picocell can find at least 1 PF to connect to. As the number of SHRs increases the DoR of the 2 failure case and 3 failure case decreases. This is because by adding more SHRs in each picocell, the network resources will be consumed and not all SHRs in each failed picocell will succeed to get enough resources. Also it can be seen that further increase than 4 SHRs per picocell introduces negligible improvement and the DoR is almost constant. In the next scenario, the picocells SHRs will be fixed to 4 SHRs.

3) Femtocell Failure: We observe from Fig. 6 that when femtocells have only 1 SHR, the DoR of femtocells is up to 50%. This is because the femtocells most of time are recovered from other BSs which have much higher rates. This also explains the reason for exceeding the 100% DoR for femtocells having 3 SHRs or more. Using 2 SHRs can recover up to 90% of the failed femtocell rate which is acceptable rate in the presence of failure. Recovering more than 100% is not acceptable from the operator point of view. As the number of SHRs increases, the DoR of 2 failures and 3 failures decreases which is similar to picocell multiple failure case. Even in case of 3 failures, the DoR is approximately 85% using 2 SHRs. This indicates that our approach is robust under multiple failures.

VIII. Conclusions

We proposed a new back-haul SH approach to address the unexpected back-haul failures in 4G/5G HetNets. Our approach adds to the network BSs SH radios, whose cost is negligible compared to the cost of the BS, which used CR concept to utilize the network spectrum and mitigate interference. Simulation results show that our approach can immediately recover the failed BS partially from failure until it returns to its normal operation and this is done under single and multiple failures. Our approach recovers at least 10% DoR for all failed BSs under multiple failures using only 1 SHR in each type of BSs. To employ our approach in future 5G networks or the upcoming 3GPP releases to achieve a better DoR, it is recommended to imbed 3 SHRs in each macrocell sector, 4 SHRs in picocells and 2 SHRs in femtocells.

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