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A Survey of Self-Organizing Networks (SON)

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ABSTRACT: With the rapid growth of mobile communications, deployment and maintenance of cellular mobile networks are becoming more and more complex, time consuming, and expensive. In order to meet the requirements of network operators and service providers, the telecommunication industry and international standardization bodies are paying attention to the research and development of self-organizing networks. In this report, we first discuss about when and why SON was introduced. Discuss about the aspects of SON. Further we learn about the various use cases of SON in which we will discuss about critical issues and their solutions pertaining to topics like Automatic Neighbor Relation(ANR), Load balancing, Energy saving, Coverage and capacity optimization.

KEYWORDS: Cellular network, self configuration, self optimisation, Load Balancing, Remote electric tilt.

I. INTRODUCTION

Radio access elements account for a large share of cellular network's installation, deployment, and maintenance costs. The usage of advanced access and transmission techniques, both the transmission bandwidth and quality of service (QoS) of mobile networks, need to be improved since new wireless service models and applications have been developed and also due to the increasing spectrum band and data rate. This is why efforts to introduce SON focus on the network's radio access assets first. Moreover, the deployment and optimization of mobile networks are very complicated and challenging engineering tasks that require a comprehensive systematic approach. Conventional procedures usually cost a long time, and a lot of resources and manpower to do this. The revenue from a mobile network highly depends on its operational efficiency. Hence, operators need advanced technologies and proper strategies to reduce the OPEX of LTE networks. Thus, introduction of SON has helped reduce the capital expenditures (CAPEX) and operational expenditures (OPEX) through Self-configuration, Self-optimization and Self-healing.

The requirement to meet the needs of both users and operators in a cost effective way has triggered research to add *intelligence* and *autonomous adaptivity*, dubbed holistically as Self Organisation (SO), into future cellular networks. This initiative is mainly motivated by the following factors.

a. Although best possible capacity of the wireless channel is known to have physical upper limits, the inherently unpredictable nature of spatio temporal dynamics associated with wireless cellular systems, makes even this optimal performance in terms of capacity and QoS unachievable with fixed legacy designs, as it lacks flexibility to intelligently adapt to the dynamics cellular systems face. Therefore, due to the mobility of users and the varying nature of the wireless channel, systems suffer from the under utilisation of resources resulting in either low resource efficiency or over utilisation which results in congestion and poor QoS, at varying times and locations.
b. With the recent advent of Femtocells, and increasing deployment of outdoor relays or Pico cells in the search for capacity and QoS, the number of nodes in future cellular systems will be too large to be configured and maintained for regular operation, with classic manual and field trial based design approaches. This is particularly true for Femtocells as they will be deployed in an impromptu fashion with plug and play capabilities and can thus cause severe interference resulting in degradation in performance of neighbouring macro cells, if not equipped with self organisation.
c. Given the huge scale of future wireless systems, the classic approach for periodic manual optimisation required during the life time will cease to be efficient. Also the increased complexity of systems will lead to greater human errors which will result in longer recovery and restoration times.
d. Finally, in addition to improved performance, SO can reduce the OPEX significantly as it eliminates the need for expensive skilled labour required for configuration, commissioning, optimisation, maintenance, troubleshooting and recovery of the system.

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SO is effectively the only viable way of achieving optimal performance in future wireless cellular networks in a cost effective manner. Standards for Long Term Evolution (LTE) and LTE-Advanced [1]have therefore identified self organisation as not just an optional feature but an inevitable necessity in these future wireless systems[2].

II. SCOPE OF SELF ORGANISATION IN WIRELESS CELLULAR NETWORKS

This section provides a brief timeline for literature on SO in cellular networks in order to build a foreground for detailed categorical survey in following sections. We also summarise the major applications (use cases) of self organisation and conclude this section by presenting a set of possible taxonomies that can be used to classify different types of self organising solutions presented in the realm of cellular systems.

A. Major Use Cases of SO

Use cases are descriptions of the functionality that can be achieved through self organisation. They elaborate the objectives for which self organising algorithms are to be designed. In the open literature, as well as projects and standardisation activity, a number of use cases has been identified. For example SOCRATES [3] presented an extensive list of 24 use cases most of which overlap with the use cases identified by 3GPP [4] and NGMN [5]. Most of these use cases can be summarised under the following 9 specific categories

1. Coverage and capacity optimisation
2. Energy saving
3. Interference reduction
4. Automated configuration of physical cell identity
5. Mobility robustness optimisation
6. Mobility load balancing optimisation
7. Random access channel (RACH) optimisation
8. Automatic neighbour relation function
9. Inter-cell interference coordination

All the aforementioned use cases can be classified under one of the four main system objectives i.e. Coverage expansion, capacity optimisation, QoS optimisation and Energy efficiency all riven by the basic motive of cost optimisation as shown in Fig. 1. It must be noted that these use cases and their main objectives have strong coupling with each other making the optimisation of one difficult without compromising the others [23]. This coupling is further discussed in the following sections.

B. Taxonomies for SO in Wireless Cellular Systems

With a clarification of the characteristics of SO and applications relevant to cellular communication systems, we present a taxonomy under which such systems can be studied. Three main classification regimes have been identified

1. Time scale based classification: Cellular communication systems have a set of different scale dynamics as explained in F. Therefore, different self organising algorithms designed to cope with these dynamics have to operate on respective time scales. e.g. adaptive modulation and coding scheme algorithms operates on a micro second scale [7] whereas a power control based load balancing algorithm might operate on time scales of minutes and hours whereas adaptive sectorization algorithms might operate on the scale of days and months . This different diversity of times scales can be used to classify SO. Although, this is the simplest taxonomy as it does not describe much about the scope or objectives of the algorithms.
2. Objective or use case based classification: Each SO algorithm can be classified using categories of use cases. But the problem with this approach is that one algorithm can have multiple use cases, e.g same self organising algorithm that aims for load balancing can optimise capacity as well as QoS.
3. Phase based classification: There are three clear phases in the life cycle of a cellular system i.e. deployment, operation, maintenance or redep loyment. Holistically, self organising solutions/algorithms can be classi fied with respect to each of these phases. The algorithms that self organise these three phases can be classified into self configuration, self optimisation and self healing.

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III. UNDERSTANDING SELF-ORGANIZING NETWORK (SON)

The 3GPP standardization body introduced SON in its December 2008 Release 8 while drafting LTE specifications. The main functions of SON are:

1.Self-configuration:

Self-configuration process is defined as the process where the newly deployed eNBs are configured by automatic installation procedures to get basic parameters and download necessary software for operation. Self-configuration process works in pre-operational state, which starts from when the eNB is powered up and has backbone connectivity until the RF transmitter is switched on.

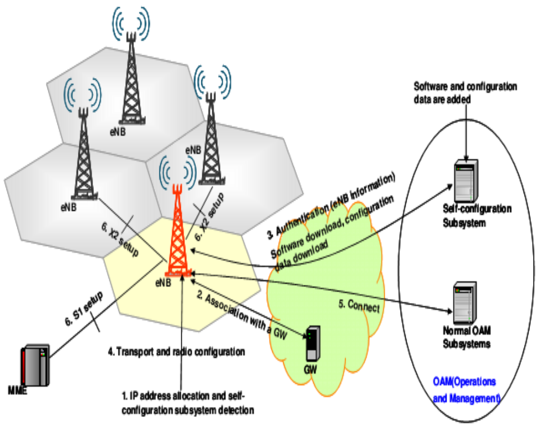

Figure 2: Self-configuration Procedure

With respect to the above figure, the procedure of self-configuration is given as follows:

1. An IP address is allocated to the new eNB and the information of the Self-configuration Subsystem of OAM (Operation and Management) is given to the eNB.
2. A GW is configured for the new eNB so that the eNB can exchange IP packets with other internet nodes.
3. The new eNB provides its information, including type, hardware and etc., to the Self-configuration Subsystem for authentication. Necessary software and configuration data are downloaded from the Self-configuration Subsystem.
4. The new eNB is configured based on the transport and radio configuration data.
5. The new eNB connects to the normal OAM subsystems for other management functions.
6. S1 and necessary X2 interfaces are established.

2.Self-optimization

Self-optimization process is defined as the process where UE & eNB measurements and performance measurements are used to auto-tune the network. This process works in operational state, which starts when the RF interface is switched on. The self-optimization process collects measurement information from UE and eNB and then with the help of external optimization tool, it auto-tune the configuration data to optimize the network. A typical example is neighbor list optimization.

3.Self-healing

Self-healing functionality monitors the alarms, and gathers necessary correlated information (e.g. measurements, testing result, etc.) and does deep analysis, and triggers appropriate recovery actions to solve the fault. It also monitors the execution of the recovery actions and decides the next step accordingly. Auto-restart and other automatic alarm features allow the network operator even more quick-response options.

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IV. SELF OPTIMISATION FOR LOAD BALANCING

The need for load balancing mechanisms to mitigate the effects of natural spatio-temporally varying user distributions was realised immediately after the advent of commercialised cellular communication systems. A large number of research papers since then have addressed this problem and have proposed a variety of very useful load balancing strategies some of which even reach the required level of scalability, stability and agility and achieve the desired SO behaviour. However, the problem lies in the fact that, most of these schemes were specific to the particular generations of cellular systems evolved so far and only a few are applicable to the emerging systems (e.g. LTE and LTE-A) due to the differences in the MAC and physical layer. In the following subsections we discuss the key papers by broadly classifying them in four general categories based on the main underlying approach they take towards Load Balancing (LB). i.e. 1) Resource Adaptation based LB, 2) Traffic Shaping based LB 3) Coverage Adaptation based LB, and 4) Relay assisted LB.

1) Resource Adaptation (RA) based LB : In this scheme, the main underlying principle is to adapt the amount of resource allocated to a cell to match it to the offered traffic load in that cell for optimal LB. More specifically an over loaded cell would borrow channels from other cells that are less loaded or from a common pool of free channels. References [8]–[11] present various load balancing schemes building on this main idea. Authors in [10] presented and evaluated the performance of channel borrowing algorithms where an over loaded cell borrows channels from selected cells that are least loaded. The authors further refined the idea in [10] and presented in [8] an improved version in terms of scalability by limiting the borrowing process within the hierarchical tier based local structures or clusters, although at a cost of loss in performance due to lack of global optimality in this distributed approach. The scope of these schemes has been limited to legacy GSM type systems where neighbouring cells use different frequency channels. In the case of emerging OFDMA based cellular network (LTE and LTE-A), frequency reuse of one prevails, and such channel borrowing will cause intra-cell interference that is not otherwise present in OFDMA based systems. However, some authors have attempted to extend the channel borrowing concept to make it applicable to CDMA based cellular networks by introducing the idea of virtual channel borrowing for CDMA based systems [12]. The basic concept of channel borrowing has also been extended for emerging cellular systems by generalising it in the form of bandwidth management strategies [9], [11]. While the work presented in [9] remarkably exhibits all the desired features of SO i.e, scalability, agility and stability, due to its cell by cell implementation style, its lack of pragmatism for wireless cellular systems with universal frequency reuse undermines its applicability. Arguably this is the reason such schemes have not been further investigated in the context of LTE and LTE-A.

2) Traffic Shaping based Load Balancing: In these schemes the main underlying principle is to shape the traffic offered to a cell either through pre-emptive and strategic *admission control* or forced *handover* of the *on going* calls in order to effectively match the offered traffic load with the available resources for optimal Load Balancing (LB). A number of papers have focused on optimising such traffic shaping strategies to minimise trade off in terms of hand over overheads and interference. These papers all refer to the pioneering paper that presented a simple but seminal idea of selecting least loaded cells among candidate neighbour cells for handover based on LB. A comprehensive review of LB balancing algorithms using the traffic shaping approach and other approaches have been presented in along with a general mathematical framework that models the underlying principles of a variety of LB strategies. Although call admission is also a possible way of traffic shaping , due to the randomness of arrival times and user mobility, its use for optimal load balancing is a relatively complex approach that necessitates extensive cooperation among cells to ensure QoS, so that the call rejected by one cell is accepted by others. On the other hand, handover parameter adaptation to trigger forced handovers of ongoing calls to shed extra load to neighbouring cells, is a more straightforward approach.A handover based approach for LB exclusively for LTE. The algorithm requires all cell loads to be known at the central control unit and optimal handover parameters are determined based on it. Simulation results show that load can be balanced to a reasonable degree across cells with this approach. Signalling overhead and excessive delays incurred due to a centralised nature, that might compromise scalability and agility of the algorithm, are not thoroughly explored in this work. It is important to mention that, in the case of LTE and LTE-A, HO based traffic shaping is not as feasible an approach as it was for CDMA based UMTS. This is due to the fact that in OFDMA based systems such as LTE and LTE-A, the luxury of soft and softer handover is not available and hard handover usually involves a change of

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carrier frequency incurring extra complexity and overheads. This makes the majority of the existing solutions based on the traffic shaping approach less attractive for LTE and LTE-A.

3) Coverage Adaptation based Load Balancing: These schemes rely on mechanisms to change the effective coverage area of the cell to match the traffic offered with the resources available either through *power adaptation*, *antenna adaptation* or a *hybrid* of both techniques. This approach has been most extensively studied in the literature because of its flexibility, and effectiveness and in the following subsection we discuss the key papers by further classifying them into the three sub categories listed above.

a) Load Balancing via Antenna Adaptation: In these schemes the basic idea is to reduce the coverage area of the over loaded cells either through tilting down the antenna [13] or by changing its radiation pattern [14]–[22]. Authors in [14]–[16] consider a scenario with traffic hot spots that cause congestion in some cells and propose a solution that contracts the antenna patterns of the congested cells around hot spots, whereas neighbouring cells expand their radiation pattern to fill in any coverage gaps. These three papers by the same authors, assume negotiation among only neighbouring eNB to fill in any coverage gaps and thus have basic scalability, but at the cost of the stability as coverage gaps may be left uncovered with such limited local cooperation. In [17], the same authors attempt to address the coverage gap issue by using a bubble oscillation model where air in the adjacent bubbles fills any gap among adjacent bubbles via oscillation of the bubbles. There may be a serious compromise on agility and stability in general (non cooperative) OFDMA based cellular systems because of the hard handovers involved as discussed above. In [19] again, the same authors present a solution in the context of WCDMA instead of CDMA.

   Authors in [18] compare the impact of cooperative beam shaping with the cooperative tilt adaptation for LB. The tilt based approach has relatively less margin for performance improvement but it is more pragmatic as it is implementable with conventional widely commercialised parabolic antennas [13].

b) LB through Power Adaptation(PA): In these schemes, the coverage is adapted for LB through control of transmission power of the signal carrying the cell signature that is used by the users for *cell association*. This is different from the handover parameter control used for traffic shaping discussed in subsection V-A2 . In contrast to traffic shaping through forced handovers, coverage adaption through power adaptation does not only affect the ongoing calls, but effectively changes the coverage area and thus changes the association of all users in the coverage area. Only a few papers have reported work in this area [23]–[28].

   Authors in [23] present a *centralised* scheduling algorithm wherein users may switch eNB in every time slot with the joint objective of throughput maximisation and LB simultaneously. Authors in [23] also assess the heavy overhead of this solution that makes it void of scalability and agility, and therefore propose a lighter version of the algorithm. They suggest separating LB from throughput maximisation and thus the time scale of the eNB switching for LB alone can be increased to several time slots such that it is just enough to cope with user mobility, rather than in every single slot as required for throughput optimisation. This solution reduces the signalling overhead, making it relatively more scalable, however central control is still required in this solution.

   Only [25]–[28] consider an OFDMA based systems and propose algorithms for dynamic association or coverage adaptation. References [25] and [26] use coverage adaptation or dynamic association, as termed by the authors, for joint objective of load balancing and interference avoidance through fractional frequency reuse. While this scheme shows significant gain in terms of designed utility as an indicator of system wide performance, the underlying assumption of network wide feedback and channel estimation, at each MS and eNB at each scheduling instant and the need for a central control entity, makes this solution lacking in scalability and agility required for self organisation. Authors in [27] proposed a similar algorithm that is again purely centralised and thus lacks scalability and agility.

c) LB through Hybrid Approaches : In addition to the papers discussed above, some authors have used multiple approaches to LB simultaneously. Authors in [29] presented analysis for the simultaneous use of traffic shaping through both call admission control and handover hysteresis control and coverage adaptation through both antenna adaptation and TA for general TDMA/FDMA systems. While simulation results report 3-11% network wide gain in performance the proposed methods lack scalability because of the requirement for a central control unit that needs to exchange excessive signalling with all users in the network to obtain spatial traffic estimates. Furthermore, the dependency of the proposed methods on the use of mobile positioning jointly with cell assignment probability maps (generated by the network planning process) for spatial traffic estimations makes it less agile in dealing with the spatio temporal dynamics of cellular communication systems. It is thus more of an

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offline design methodology, more useful during the deployment phase, than an online LB mechanism implementable in the operational phase. Authors in [30] proposed a similar centralised LB algorithm for CDMA based systems that use both antenna adaptation and power adaptation together. As highlighted by the authors, this is time consuming and hence not agile enough to be used for real time LB. Rather its use as a self healing scenario has been proposed by the authors. Furthermore, it is important to mention that this algorithm is also centralised and hence lacks scalability.

4) Relay Assisted LB: In addition to the approaches discussed above, relay assisted cellular networks have also been extensively investigated as possible LB tools [31], [23], [30]–[31]. This is due to the fact that relay nodes can help achieve LB via at least three different means. 1) Through coverag e adaptation, by improving coverage and signal quality at the point of interest e.g hot spot. 2) Through resource adaptation by local or opportunistic reuse of spectrum. 3) Through traffic shaping by relaying or routing traffic from over loaded cells to less loaded cells. The last of these three approaches has been most extensively investigated in literature [28]–[30], However, most of these approaches assume CDMA cellular systems with ad-hoc relays operating on an out-of-band spectrum e.g. ISM. As highlighted by authors in [32] the realistic performance of such ad hoc systems in terms of dynamic load balancing and load sharing is heavily dependent upon the number of channels available to the ad hoc relays. It is concluded in [32] that for dynamic load balancing the number of such channels required is much more than those required for load sharing (improving the call blocking probability of a hot spot to 2%).

Authors in [33] and [34] are the only ones to consider relay stations with inband spectrum and of a non adhoc nature for LB in a fully architecture based OFDMA cellular system. The main idea in [33] is that all users establish their association with the base station or relay station dynamically to maximise a utility function designed to reflect system wide performance. It is further proposed that relays also establish their association with the eNB's to maximise the same utility. Stability of the system is ensured by confining the reassociation process to one relay node and UE per time slot to avoid a ping pong effect. Substantial improvement in user throughput is reported with the proposed scheme. Although most of the information exchange required is local among neighbouring cells.

Authors in [34] exploit the idea of dynamic clustering through cooperation among neighbouring cells thereby avoiding need for central control unit to keep solution scalable. They introduce a dynamic clustering approach, where overloaded cells form clusters by selecting from the 6 neighbouring cells those with the least load. The traffic to be transferred from the over loaded cell to the other cells in the cluster is determined and transferred for LB. The performance of this algorithm is evaluated for a hypothetical scenario where only one central cell is over loaded and a more realistic evaluation is indicated as future work. It is anticipated that in the more realistic scenario, where multiple over loaded cells may coexist, this dynamics clustering approach might need to be improved as it may have stability issues when the same cells are neighbours to more than one overloaded cell resulting in a ping-pong effect in the clustering process.

V. OPTIMISATION TECHNIQUES

Although some form of learning and emergent intelligences exhibited by natural SO systems this intelligence may arise by following simple optimal rules at local entity levels in the system rather than a complex learning process across the system as a whole. Therefore, classic optimisation is an equally promising approach towards designing SO in future cellular systems as long as it can yield solutions that are scalable, stable and agile. Scalability and agility usually demand that the optimised solution should be implementable in a distributed manner. Stability requires that it should be optimal or at least feasible for all potential states of the system. i.e. The optimisation process might have to consider multiple objectives simultaneously or be bounded by feasibility constraints as optimisation of a single objective, while neglecting others may lead to unstable or non pragmatic solutions. Below we discuss both kinds of approaches.

1) *Distributed Optimisation:* If the system wide optimisation objective of the SO, can be broken down to local optimisation functions to be addressed by local entities in the system, optimisation of which is dynamically maintained by each of the entities independently or semi independently, an adaptive scalable, stable and agile solution can emerge i.e. SO can be achieved that can manifest automaticity just as in a school of fish. While this approach seems deceptively straightforward, its hidden difficulty lies in the transformation of system wide objectives into local functions that are

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simple (agility), will not require global cooperation (scalability) and yet still merge into a consistent global behaviour (stability).

2)

2) Multi-objective Optimisation: Cellular communication systems are inherently complex as a change in one system parameter intended to control one objective has an effect on other objectives. For example, increasing the transmit power in a cell would increase its coverage but also increase the inter-cell interference which in turn will decrease capacity and may effect energy efficiency as well. Therefore, as discussed above, in order to ensure stability of the SO solution classic single objective optimisation techniques have to be extended to take into account multiple objectives either as simultaneous optimisation objectives defined feasibility constraints.

VI. CONCLUSION

A deep understanding of what the SON new functionalities of future networks are, Coverage and capacity optimization use case by means of the adaptive adjustment of RET and antenna direction. The self-optimization of antenna tilts and directions may provide significant performance improvements in instances of suboptimal network planning or reuse of 3G network planning, and/or varying radio network environment conditions.

The evolving mobile business demands broadband mobile networks with high operability as well as high performance. A promising solution is SON as it allows operators to implement objectives such as robustness, better performance, and energy efficiency at a lower cost than that of traditional management approaches. SON solution will enhance robustness, scalability and response of the self-Optimization functions and enable effective integration into the existing operations. Furthermore, the self-optimization with a radio planning tool such as Remote Electrical Tilt, will powerfully enhance the user's experience.

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