Addressing Spectral Congestion with Cognitive Radio and Open Access

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Abstract: Cellular operators are currently facing congestion in certain spectral bands due to high service demand. Amongst the various approaches to solve this being proposed, Cognitive Radio approach aims to solve the problem of spectral congestion by load-sharing wireless traffic across different spectrum bands. However, a much more powerful and cost-effective approach called as "Open Access" is presented here. It proposes to load-share the traffic across any infrastructure network, fixed or wireless, license or license-exempt and to decouple the tight nexus between spectrum, technology/service and network infrastructure. It is thought that such an approach will be able to prevent spectral congestion for the foreseeable future for a significant number of users without having to resort to the relatively complex approach currently used by cognitive radio. The paper proposes a functional representation of the communication industry based on Open Access. However, the new approach is still the subject of ongoing research, so the main aim of this paper is to provide a conceptual understanding based on qualitative arguments which are supported with some early evidence.

1 Introduction

With the phenomenal success of video-on-demand services such as Google's YouTube and BBC's iPlayer, there is an ever-increasing demand for mobile data traffic. Wireless services have become pervasive with millions of devices attached to the internet. Data-rates are continually rising due to the proliferation of high-end devices like iPhone, iPad, etc. It is estimated over the next five years, the amount of data traffic is expected to increase at least 35-fold [1]. As a consequence, operators are facing congestion in certain spectral bands. On the contrary, several recent measurements surveys [2] have shown that numerous other bands are massively under-utilised at the same time. To understand the reasons for concurrent occurrence of congestion and under-utilisation conditions, the author believes following reasons to be the fundamental cause,

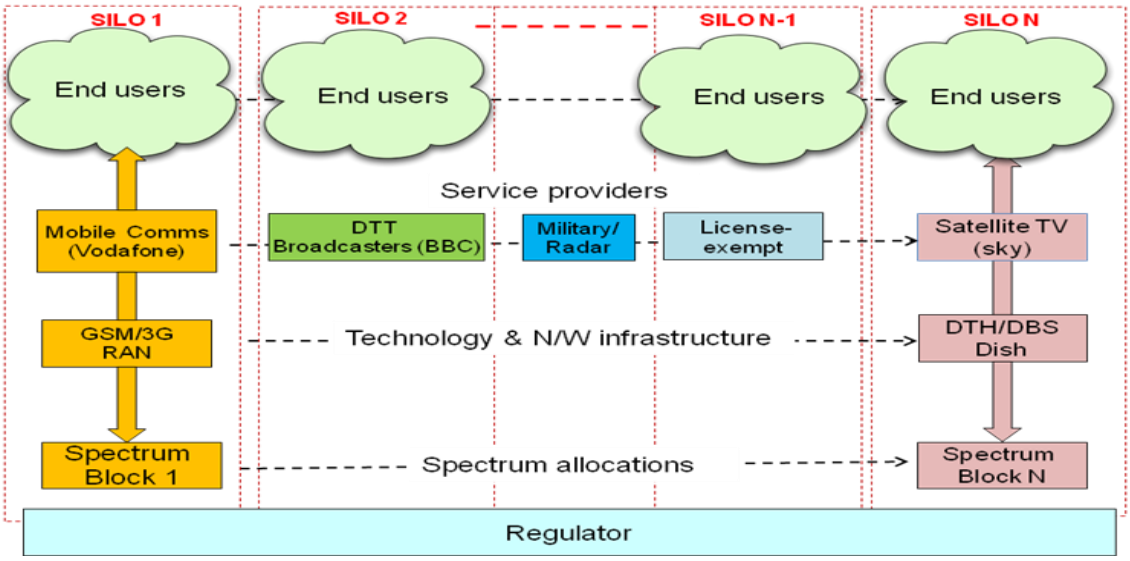

Fig 1: Current service provisioning structure that illustrates a tight coupling of service, technology, networks with spectrum

To support specific business models a rigid vertical stove-piped infrastructure model has evolved over the years/decades in the wireless industry. This is reflected in Figure 1, where the technology, network infrastructure, applications and spectrum are silo'ed and as a consequence, each service provider has built a network control and service intelligence tied to particular type of network and spectral band. This has resulted in a tight coupling of technology, infrastructure and services with spectrum. The coupling results in spectrum being locked in a particular silo and when some services are unsuccessful the spectrum remains under-utilised for a long duration. Examples include failure of European Radio Messaging System (ERMES) paging, Terrestrial Flight Telephone System (TFTS) in-flight phone system resulting in the allocated spectrum never being used when emerging technologies/services like WiMAX and Mobile TV were unable to get adequate spectrum in the UK.

Along with this, the current spectrum management framework issues spectrum licenses that are fully defined to narrowest level using a command and control administrative practice. This form of licensing gives exclusive rights to manage interference by specifying detailed rules and constraints affecting how, where, when and who has access to spectrum and transmission rights. Though, the current framework is a good way to control interference especially when the radio technology was not fully mature, there is a growing consensus that it has delayed introduction and growth of emerging technologies. It is rigid and unresponsive to any imbalances of traffic demand and spectrum allocations. Regulators a-priori have to determine the amount of spectrum needed for a particular technology and service mix and thereafter the issue licenses to operator and technology, for a set duration. As complexities of wireless access technologies increase a new multi-disciplinary approach to spectrum management is needed. This limitation is understood and being addressed as evident from the recent rulings by FCC and Ofcom [3], [4], by enabling dynamic transfer of excess spectrum from underutilised bands to congested bands with concepts such as spectrum trading and spectrum liberalization [5]. This paper restricts itself to the technical side of the spectral congestion argument. The congestion problem is approached by structuring the paper as follows. Section 2 and 3 discusses the two approaches to alleviate the congestion problem - cognitive radio approach and an alternate approach called as Open Access (OA) respectively; followed by conclusion in section 4.

2. Cognitive Radio Approach

Cognitive radio (CR) technology [6, 7, and 8] aims to alleviate the congestion problem by enabling access to under-utilised spectral bands on an opportunistic basis. It enables frequency hopping across spectral bands to perform the load balancing. For example, as seen in Figure 1, if congestion occurs in a 'mobile comms' spectral band, the cognitive radio device could somehow identify an under-utilised frequency, say a 'Digital Terrestrial Television (DTT) broadcast' band, hop to it and use the DTT spectrum, provided such secondary use of spectrum does not interfere with the broadcast system. There are certain areas that are not addressed by the current CR vision which are now discussed here.

Cognitive radio has omitted to include of fixed network connectivity as an option to avoid congestion. The reasoning behind this is that when spectral congestion occurs it is very likely that a significant number of the users will be at locations where they could just as easily have used fixed (direct or over a short wireless hop up to several metres long) rather than pure wireless connectivity (a wireless hop in excess of several tens of meters long). In fact, wireless traffic surveys show that approximately 75% of wireless traffic originates indoor/in-building environment [9]. Therefore, it should be possible to avoid spectrum congestion for a significant number of users by off-loading them onto a fixed network rather than load balancing them across a number of underutilised licensed spectrum bands. Inclusion of fixed-line connectivity as an option could potentially remove the need for conventional cognitive radio solution in such locations. Secondly, cognitive radio approach fails to address the decoupling as users would continue to be locked-in to particular service providers, network infrastructure and spectrum, retaining the stove-piped industry structure as highlighted in the figure 1. Ideally, all end-user-services should be completely decoupled from the underlying physical network and spectrum. As a consequence CR can only prevent spectral congestion in regions where a number of different, co-located and co-operating wireless networks exist. Finally, as frequency is not a homogenous resource, applicability of cognitive radio technology may be limited to certain frequency bands. This is due to certain physical and technological constraints like device size or capability; for example, antenna size significantly increases with reducing frequency or has to be traded against gain for handheld devices.

This has implications for the usefulness of releasing lower frequency spectrum for certain services or devices. Similarly, increasing frequency results in use of higher transmit power due to reduction of range. This has implications on the usefulness of releasing higher frequency spectrum for mobile services due to transmit power limitations of practical device design that is, if the transmit power of mobile devices will remain in the region of 20 to 30dBm. Though cognitive radio technology is currently heavily researched, it may be difficult to achieve a solution within the timescale that it is envisaged that spectral congestion will become a significant problem. To address the above limitations, the author proposes an alternative approach called as Open Access (OA) as discussed in the next section.

3. Open Access Approach

Open Access proposes following ideas to address the congestion problem. Firstly OA proposes to extend current CR vision to include fixed-line connectivity as an option whenever possible along with conventional wireless options to solve the congestion problem (for reasons stated in previous section i.e. when 75% of wireless traffic originates indoor environment [9]). OA thus offers a wider choice of connectivity, use of fixed or wireless ingress/egress to perform traffic load balancing under congestion scenarios. This would require specifications for the new control protocols and access intelligence functions that will be needed to enable commodity connectivity. Secondly, to solve the spectral congestion, the author believes a complete decoupling of services and access connectivity should happen and user service, in principle should be delivered over either wire or wireless. OA proposes spectrum to be treated equivalent of fixed-line in an open and flexible manner, which could be achieved by extending the fixed local loop unbundling[1] concept to the wireless called as wireless unbundling. The reasoning behind this is that all devices are effectively connected to a network by a single-hop ingress/egress link, which can be either wire or wireless. In principle, this is simply a bandwidth connection that does not have, and does not need to have any knowledge of the service(s) carried. It is the design process that requires knowledge of what types-of-service will be carried so that the ingress/egress link can be dimensioned accordingly. Consequently, the basic link connectivity provided by any service/technology mix like LTE, WiFi, DVB, etc., is only limited from a service perspective if it cannot provide sufficient bandwidth. On the other hand, the ability of devices to process content such as audio, video, pictures, text, data etc., is fundamentally independent of the underlying network technology. Therefore, it is simply the processing capabilities of a user device that determines the types of service that can be used. In principle then, types of services and types of connectivity are conceptually independent, although the bandwidth limitations of some technologies will prevent the ingress/egress links from being able to carrying some types of services.

Based on the proposals suggested above, the functional representation of the communication

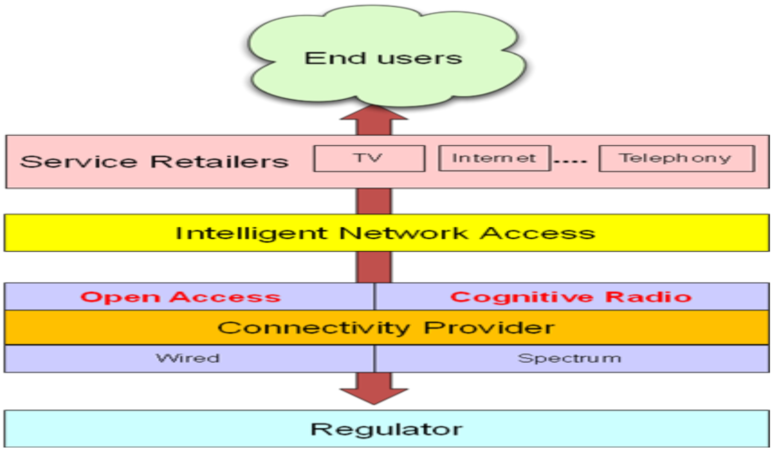

Figure 2: Proposed Open Access architecture

[1] The local loop unbundling approach has been adopted in the fixed-line networks in the UK and under this concept, the fixed-line access connectivity is separated from the service providers and any third party can negotiate access to certain amount of capacity based on their requirements.

industry would probably have a structure similar to that shown in Figure 2. The new role or functionality of each of the four stakeholders is briefly listed here.

- Regulatory role under the OA model is to regulate the connectivity network (fixed and wireless) such that it is operated in the best interests of end users and service retailers. Current service providers such as mobile network operators or broadcasters would relinquish control of their spectrum to Connectivity Providers through some regulatory/ commercial arrangement. However the main challenge for the regulator under the OA model is to provide incentives and penalties such that there will be sustained investment in connectivity infrastructure.
- Connectivity Provider is mainly responsible for investing, maintaining and managing the infrastructure to meet the capacity demands of Service Retailers and is only allowed to sell connectivity via wire and wireless. The connectivity market is a regulated market which manages the Service Retailer's and the only concern of Service Retailers is to specify particular service requirements such as location, bandwidth, latency, duration, speed of movement, cost, etc negotiating access rights. It provides aspects of intelligence needed to satisfy Service Retailer requirements with "Open Access" and "Cognitive Radio" [10] running as network services as shown in Figure 2. One potential benefit from a Connectivity Provider point-of-view when connectivity is driven to become a commodity is that it would avoid any infrastructure duplication.
- The Intelligent Network Access layer separates connectivity and service control intelligence and creates an open information and intelligence platform that underpins all applications and services [11], [12] and [13].
- Service Retailers procure connectivity from Connectivity Provider and service-agnostic information from Intelligent Network Access layer to blend and adapt range of services comprising any mix of video, audio, pictures, data, text etc.

4. Conclusion

The Open Access proposal made in this paper claims to provide a more cost-effective solution to Cognitive Radio approach to solve the spectral congestion problem. It highlights current limitations of the cognitive radio approach, mainly failure to provide a wider choice of fixed-line connectivity and failure to enable decoupling of spectrum from services/technology/infrastructure as addressed by OA approach. OA proposes connectivity to be treated as a commodity irrespective of whether it is wired or wireless leading to a functional representation of the industry architecture shown in the paper. This would enable creation/managing of an ideal type of communication infrastructure network and ensures the connectivity requirements of a dynamic mix of services is met of service retailers. Migrating to the proposed OA model is a political/commercial decision that the regulator would have to make whenever the current spectrum licenses expires. Further research is needed to provide insights into the impact migrating to Open Access model is likely to have on overall aspects such as operating costs, regulation, technology, operators, users, etc.

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