COOPERATIVE COMMUNICATIONS AND NETWORKING: CASE STUDY ON CROSS-LAYER DESIGN AND OPTIMIZATION OF COGNITIVE RADIO NETWORKS

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***Abstract*: Today wireless technologies simply coexist without any coordination (within one technology as well as among different technologies). This leads to more and more unwanted and uncontrolled interference, and hence inefficient spectrum usage, which is getting more problematic as the density of wireless devices increases. Radio spectrum is the most valuable resource in wireless communication. The cognitive radio and cognitive based networking are transforming the static spectrum allocation based communication systems in to dynamic spectrum allocation. Cognitive radios are intelligent devices with ability to sense environmental conditions and can change its parameters according to the requirements to get the optimized performance at the individual nodes or at network level. This paper covers the basics and origin of software defined radio, cognitive radio, cognitive radio network, cognitive cycle, signalling, Cognitive Radio Sensor Networks and the concept of cross layer design. The performance metrics explain the node and network level performance measurements. This paper also covers the different network paradigms.**

***Keywords*: Software defined radio, Cognitive radio, Cognitive cycle, Cognitive networks, Cross layer design, Performance metrics.**

Current computer network technology is statically configured and it cannot adjust itself to changes on demand. Cognitive networking is a technology which allows networks to give better service to users. It is aware of networks state and usage patterns. It tries to predict and optimize data transfer based on past data, quality of service needs of users and current network state. To achieve this network needs to be redesigned from ground up to give network mechanisms to self diagnose and self adjust.

During the past decades we have witnessed the explosive emergence of wireless technologies and standards. There is a continuous evolution of wireless technologies, covering different ranges (from short range personal areas networks, local areas networks up to metropolitan area networks) and different spectral bands (both unlicensed industrial, scientific and medical bands and licensed bands). The availability of wireless networks and technologies has triggered the appearance of plenty of wireless and/or mobile devices, ranging from very small, embedded devices like wireless sensors up to more powerful devices like mobile laptops. Today wireless technologies simply coexist without any coordination (within one technology as well as among different technologies). This leads to more and more unwanted and uncontrolled interference, and hence inefficient spectrum usage, which is getting more problematic as the density of wireless devices increases.
Internet traffic increases constantly in a very fast pace, but technology behind it has not changed much in decades. Current technology is designed to simplify designs by hiding information. Network layers tell each other only what needs to be transferred and very little status information is transferred between network nodes. Computer networks are statically configured which might be highly suboptimal for many usage patterns. Routers forward packets with strict rules and knows very little of conditions of other parts of networks. Protocols cannot do intelligent decisions, only react when problem occurs. For example TCP congestion control just slows down the transfer speed when packets are lost and tries slowly increase the speed until next packet is lost. If it had knowledge of network status before transfer, it could optimize transfer speed and avoiding packet loss. Cognitive networking has a different approach. It knows status of every member of network from hardware level to protocol stack and can adjust itself to application requirements even before user sends anything. Goal is to provide optimal end-to-end performance.

A cognitive network is a network that uses cognitive processes to perceive current internal conditions, make decisions based on its findings and then learn from those decisions. A cognitive network is different from other intelligent communicational technologies because it has its own end-to-end goal regarding data flow and is designed to go beyond self-modification. Wireless link modules provide system designers with reusable open network abstractions, where the modules can be individually updated, or new modules may be added into the wireless link layer. High modularity and flexibility could be essential for middleware or application developments.

Wireless communication created a revolution in our lives. New wireless devices are capable of offering higher data rates and innovative services. Licensed and unlicensed spectrum is available for different wireless services. But with the exponential increase in wireless devices and their usage, the unlicensed spectrum is becoming scarce [1] [2]. Licensed spectrum is used for specific service while the unlicensed spectrum (Industrial, Scientific and Medical radio bands) are freely available for wireless services and research purposes. Currently static spectrum allocation policy is in practice due to which bandwidth in unlicensed bands is becoming scarce and for licensed bands it is either underutilized or unoccupied [3] [4]. Licensed spectrum specifically TV spectrum and cellular spectrum are underutilized [3].

According Federal Communications Commission (FCC) 2002, the licensed bands are underutilized and the ISM bands are over utilized [5]. This report also stated that licensed bands average utilization is 15-85% [5]. The unutilized portion of licensed spectrum is known as white space. White space could be defined by time, frequency and maximum transmission power at a specific location [2]. This spectrum inefficient utilization occurs due to static spectrum allocation policy adopted by the governments worldwide. Solution to this inefficient spectrum utilization is dynamic spectrum access and allocation. The above mentioned statistics from FCC report show ineffectual utilization of spectrum which encouraged researchers to develop new spectrum sharing methodologies.

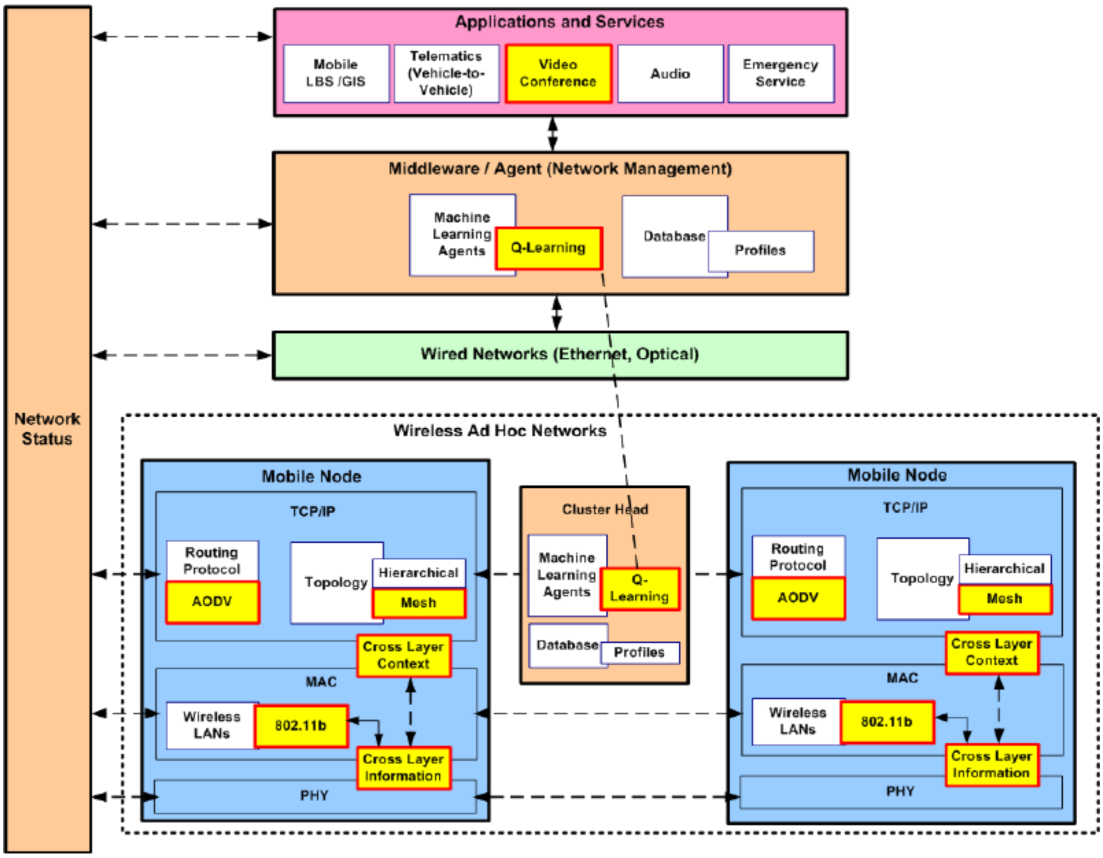
Wireless technology is proliferating rapidly, and the vision of pervasive wireless computing and communications offers the promise of many societal and individual benefits. While consumer devices such as cell phones, PDAs and laptops receive a lot of attention, the impact of wireless technology is much broader, e.g., through sensor networks for safety applications and home automation, smart grid control, medical wearable and embedded wireless devices, and entertainment systems. This explosion of wireless applications creates an ever-increasing demand for more radio spectrum. However, most easily usable spectrum bands have been allocated, although many studies have shown that these bands are significantly underutilized. Cognitive Networking (CN) and Dynamic Spectrum Access (DSA) offer the promise of dramatically improving the performance and capacity of future wireless networks.

Five types of wireless link modules were proposed, including broadcast, peer-to-peer unicast, multicast, to-sink unicast, and data aggregation, respectively. Other arbitrary types of modules may be added, establishing other types of abstract wireless links without limitation. For example, the broadcast module simply disseminates data packets to surrounding nodes. The peer-to-peer unicast module can deliver data packets from source to destination over multiple wireless hops. The multicast module sends data packets to multiple destinations, as compared to peer-to-peer unicast. The to-sink unicast module can be especially useful in wireless sensor networks, which utilizes higher capabilities of data collectors (or sinks), so as to achieve better data delivery. The data-aggregation module opportunistically collects and aggregates the context related data from a set of proximity wireless nodes.

Cognitive networks can dynamically adapt their operational parameters in response to user needs or changing environmental conditions. They can learn from these adaptations and exploit knowledge to make future decisions. Cognitive networks are the future, and they are needed simply because they enable users to focus on things other than configuring and managing networks. Without cognitive networks, the pervasive computing vision calls for every consumer to be a network technician. The applications of cognitive networks enable the vision of pervasive computing, seamless mobility, ad-hoc networks, and dynamic spectrum allocation, among others.

Current network control systems have limited ability to adapt to changing network conditions. By adding autonomous intelligence, based on machine learning, to the network management agents, it is possible to improve the Quality of Service (QoS) by reconfiguring the network management strategy around areas of interest such as user context, network state, inter-working scope and application demands. The self-configuration of network systems will have cross-layer ramifications for the protocol stack, from the physical (PHY), Medium Access Control (MAC), network, and transport layers to the middleware, presentation and application layers.

Therefore, cross-layer design approaches are critical for the efficient utilization of limited resources with QoS guarantees in future wireless networks. The recent cross-layer architectures showed that a cross-layer approach is advantageous for wireless networks. Better network system performance can be obtained from context exchanges across protocol layers. We have developed self-configuration techniques with machine learning agents in a cross-layer approach as shown in the following Fig. which could overcome the potential scope limitations of network management in heterogeneous wireless networks by allowing networks to observe, act, and learn in order to optimize their performance.



As wireless networks become pervasive, highly populated and increasingly complex, the essential preconditions for exploiting rich interactions among mobile devices are better fulfilled. Today, these trends are giving rise to new communications paradigms making use of cooperation and cognition as the main underlying principles. Cognition, together with its complementary principle cooperation, confer to the wireless networks some degree of consciousness or understanding about their own existence, such as internal structure, capabilities, relationships to the outside world, limitations, current use of radio resources and many more.

Current wireless networks are aware of their surrounding environment to a very limited extent, but in future wireless networks this capability will be highly developed, as a consequence of exploiting jointly cooperative and cognitive principles. Especially for cooperative wireless networks, where the communication scenario is highly dynamic, the mobile devices need to adapt their capabilities in a flexible manner, taking advantage of cognitive principles.

Cognitive Radios

Cognitive radios are self-aware and intelligent devices which can sense the changing environmental conditions and can change their parameter like frequency, modulation techniques, coding techniques, power etc. according to changing statistical communication environmental thus resulting in efficient utilization of available resources. Cognitive radios must be intelligent enough to learn and decide about their operating parameters and could change their transmission and reception parameters to meet performance requirements and maximize QoS. Operations of the cognitive radio are controlled by the Cognitive engine (CE).

The idea of cognitive radio provides a solution by which efficient spectrum utilization is possible by applying the optimistic spectrum sharing techniques [6]. The concept of cognitive radio was first purposed by J. Mittola in 1999 [7]. The cognitive radio is a spectrum agile system which has the ability to sense the communication environment dynamically and it can intelligently adapt the communication parameters (carrier frequency, bandwidth, power, coding schemes, modulation scheme etc.) [8].

Cognitive user should be capable of sensing the environment for the estimation of available resources and application requirements and could adopt their performance parameters according to user request and available resources [9]. Secondary (cognitive) user can utilize the licensed spectrum (available white spaces) without affecting the priority utilization of the spectrum by primary user. In this way, it maximizes the efficient licensed spectrum utilization. The hardware challenges of cognitive radio are catered by techniques like Software define radio (SDR) [10] and Application specific integrated chips (ASIC) [11].

Considering the transmission and reception parameters, cognitive radios can be divided in to two categories.

- Full cognitive radio
- Spectrum sensing cognitive radio.

A. Full Cognitive Radio

The type of cognitive radio in which almost every parameter of wireless node or network is considered [10].

B. Spectrum-Sensing Cognitive Radio

In case of spectrum sensing cognitive radio only spectrum of radio frequency is considered.

A. Cognitive Cycle

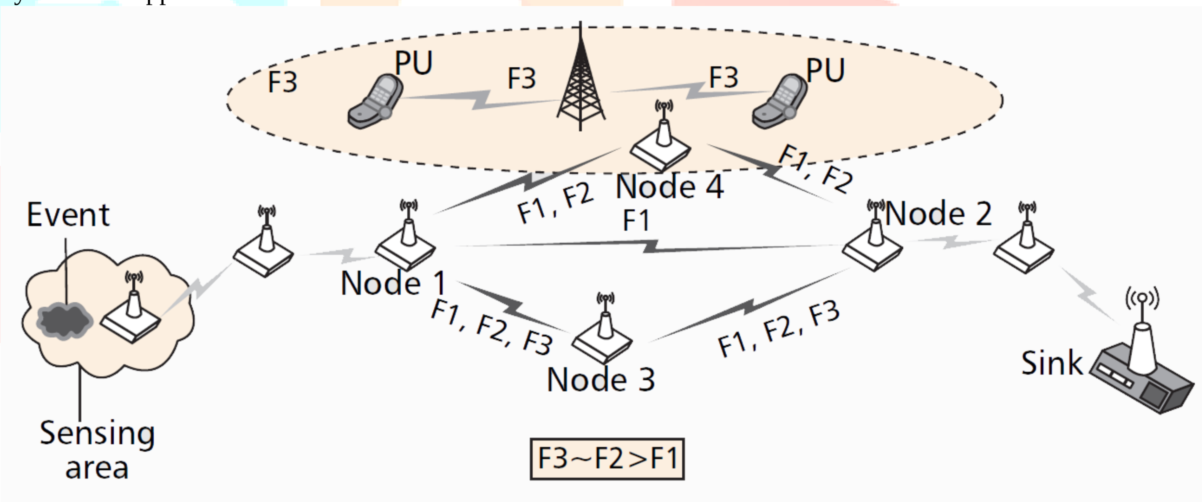
The cognitive engine works according to the cognitive cycle [7]. This cycle includes analyzing the RF stimuli from outside environment and sensing spectrum holes. It also includes functions like transmission power control and spectrum management after sensing the white spaces to ensure interference free opportunistic spectrum access.

The cognitive engine performs the tasks of sensing, analysis, learning, decision making and reconfiguration. Cognitive radio networks consist of two types of users, primary (licensed) and secondary (unlicensed or cognitive) users. Licensed users have higher priority for the usage of the licensed spectrum. On the other hand unlicensed users can opportunistically communicate in licensed spectrum by changing their communication parameters in an adaptive way when spectrum holes are available.

On the basis of incoming RF stimuli the spectrum utilization could be classified in to three broader categories black spaces, grey spaces and white spaces. Black spaces are potion of licensed spectrum being used by primary users and is occupied by high power signals. Grey spaces are temporary occupied by low power interfaces and white spaces are free from RF interferences and are purely unutilized portion of licensed spectrum. White and grey spaces are candidates for the communication of secondary user in licensed bands. As cognitive radio utilize unused licensed spectrum, thus reducing spectrum scarcity and underutilization problem of the licensed spectrum bands.

Cognitive Radio Sensor Networks (CRSN)

Wireless Sensor Networks (WSN) exclusively operates over unlicensed bands. Today, significant increase in the applications that use these bands brings about the coexistence problem. Hence, WSN needs additional capabilities to combat the interference incurred by the other applications.



A promising solution is to use the Cognitive Radio (CR) technology to arm the sensor nodes with opportunistic spectrum access (OSA) capability. Towards this end, cognitive radio sensor network (CRSN) is a recently emerging paradigm that aims to utilize the unique features provided by CR concept to incorporate additional capabilities to WSN. A CRSN is a distributed network of wireless cognitive radio sensor nodes, which sense an event signal and collaboratively communicate their readings over dynamically available spectrum bands in a multi-hop manner ultimately to satisfy the application-specific requirements.

OSA enables the use of the most suitable channel for application-specific requirements. This adaptability can also be employed to adjust transmission parameters to reduce power consumption. The existing schemes developed to obtain spectrum awareness for cognitive radios almost never consider power consumption problem, which is clearly a critical issue for CRSN.

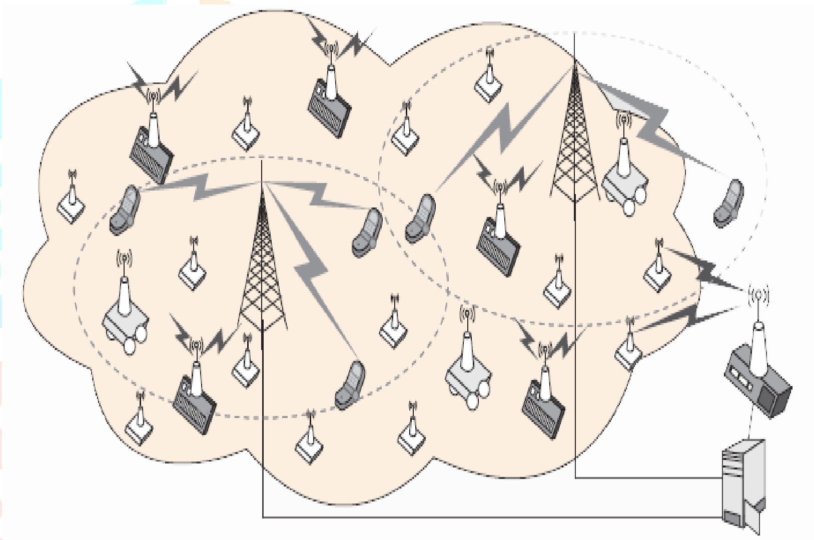
Reduced power consumption via OSA not only extends battery-constrained life-time of sensor nodes, but also limits overall energy consumption by sensor network. Thus, natural gaseous emission and dissipated heat by sensor network can be significantly reduced with the help of OSA to lead green distributed sensing networks.

There's a problem with Smart TVs - they really aren't all that smart. While having WiFi-equipped sets that can run apps and stream content from the web might make them *seem* smart, TV's don't actually know what content is onscreen when they're showing, you know, regular broadcast television. (Which is still what those TVs are most used for.) Cognitive Networks, however, has figured out how to make those televisions aware of what's happening onscreen, Like smart TVs, television networks operate in a dumb system -- once content is broadcast, networks know nothing about who's actually consuming that content or what device eventually displays it. Cognitive Networks can deliver that information to networks and telcos by installing a small script on a Smart TV that sends a constant stream of visual data of what's being displayed into the cloud.

Some companies identifies the content using Automatic Content Recognition (ACR) algorithms and notifies the TV network that its show is being watched. After getting the notification, networks can send back a URL to trigger a relevant event or open an app on your TV. They can choose certain times in the show to trigger certain notifications to perfectly tailor the viewing experience, too. Oh, and that entire process happens in less than a second.

Of course, the types of functionality will be up to the content providers to build and implement, as Cognitive Networks only supplies the infrastructure, and LG builds the TVs that gives those providers what's needed to make such features possible. So, we can expect there to be a fair share of dynamically inserted ads and promotions on sets equipped with such technology, but the good news is users can opt out if they so desire. Here's hoping the networks give us some of the helpful stuff too.

The enhanced features that Cognitive’s platform can provide are the result of a feedback loop that has been brought to viewers through a new generation of TVs connected to the Internet. Cognitive uses automatic content recognition (ACR) to figure out what viewers are watching and to serve up interactive ads and additional content targeted at what’s on the screen.



Already, Showtime is using the technology to provide additional content during its shows. Interactive elements pop up based on what’s happening on the screen, as content owners and advertisers can choose when to signal them.

How Cognitive Networks work?

Cognitive networks make use of several methods and techniques (such as machine learning techniques, decision making techniques, knowledge representation, network management, network optimization, problem solution techniques, and so on), to communicate the network devices to transfer data between them at any layer of the OSI model. They can be used to perceive the network conditions, or the user behaviour, in order to dynamically plan, adapt, decide, take the appropriate actions, and learn from the consequences of its actions.

Cognitive networks make use of the information gathered from the network in order to sense the environment, plan actions according to the input, take consciousness of what is happening in the environment, and take the appropriate decisions using a reasoning engine. Goals such as decide which scenario fits best its end-to-end purpose, or environment prediction, can be achieved with cognitive networks. Moreover, they could learn from the past and use this knowledge to improve future decisions. The application of cognitive science in data networks has affected significantly data networks advances. The book gathers recent advances in cognitive networks from the last applications and deployment perspective.

ARCHITECTURES FOR THE COGNITIVE NETWORKS OF THE FUTURE

The evolution of communication technologies, especially in the wireless domain, introduced a paradigm shift from static to mobile access, from centralized to distributed infrastructure, and from passive to active networking. Technological advances have brought networking a step forward towards the goal of service provision on an "anytime, anywhere" basis, while ensuring instantaneous and secure communications. However, such innovation is bound by the constraints included in the original Internet (and TCP/IP) design. The fundamental reason for performance inefficiency is the difficulty in configuring and managing networks – a task traditionally performed by network operators and technicians [1].

Self-awareness, self-management, and self-healing characteristics have been proposed in order to optimize network operation, reconfiguration, and management, as well as to improve data transfer performance by bringing "intelligence" into the network, thereby creating a new paradigm known as cognitive networking, which is expected to become a key part of 4th generation wireless networks (4G) [2].

The term cognitive is related to the ability of a network to be aware of its operational status and adjust its operational parameters to fulfill specific tasks, such as detecting changes in the environment and user requirements. Cognition requires support from network elements (routers, switches, base stations, etc.), which should host active tasks to perform measurements to reconfigure the network. These characteristics are related to the paradigm of active networks [3], which differ from cognitive networks service in that they do not include a cognitive process that implements adaptation and learning techniques.

The ability of cognitive network to think, to learn and benefit from past experience requires communication between cognitive elements. Cognitive network implementation can be highly distributed or tend towards centralized solutions. Common cognitive network is composed of the set of cognitive engines which may reside inside a certain protocol layer, be implemented between different layers, or be distributed between different nodes in the network.

Each cognitive agent operates locally but it also contributes into global goals by interfacing with other cognitive agents. As a result, efficiency of cognitive network operation depends on the efficiency of communication between the agents. Depending on the scope, inter-layer, intra-layer, or at the network level, different communication technologies are used which put additional constraints in terms of speed and delay of information exchange. These constraints cannot be neglected and should be taken into account during the design of cognitive network architecture and its agents.

Initially, most of the signaling techniques appeared to overcome different limitations of standard TCP/IP protocol reference model. Depending on the scope signaling techniques can be divided into two broad categories: node-level signaling and network-level signaling. Node-level signaling techniques provide the means for information exchange between different layers of the TCP/IP stack initially designed to be standalone and separated. Development of such techniques is mostly driven by the field of cross-layer design which enables a certain degree of cooperation between different layers to overcome the limitations of TCP/IP reference model.

Network-level signaling was initially designed as a part of TCP/IP and implemented using Internet Control Message Protocol (ICMP) [4] being an integral part of the IP layer. ICMP provides administrative assistance network nodes and help to determine host and route failures and other network inconsistencies.

Overview signaling mechanisms available in the literature describing their key characteristics:

A. Node-level Signaling

Interlayer signaling pipe is one of the first approaches used for implementation of cross-layer signaling [5], to allow the propagation of signaling messages layer-to-layer along the packet data flow. Signaling information, included in an optional portion of packet headers, follows the packet processing path within the protocol stack, either in a top-down or a bottom-up manner. An important property of this signaling method is that signaling information can be associated with a particular packet incoming or outgoing from the protocol stack.

Interlayer signaling pipe can be implemented using encapsulation of signaling information into packet headers, for example into an optional portion of IPv6 header [6], or using packet structures allocated by the protocol stack internally.

Direct Interlayer Communication (DIC), proposed in [5], aims at improvement of Interlayer signaling pipe method through the introduction of "signaling shortcuts" - performed out of band. As a result, DIC allows non-neighbouring layers of the protocol stack to exchange messages, skipping processing at every adjacent layer.

Along with reduced processing overhead, DIC avoids insertion of signaling information into packet headers, which makes it suitable for bidirectional communication. Signaling is typically performed using ICMP protocol.

Despite the advantages of direct communication between protocol layers and a standardized way of signaling, the ICMP-based approach involves operation with heavy protocol headers (IP and ICMP), as well as significant protocol processing overhead.

The Central Cognitive Plane, implemented in parallel to the protocol stack, is probably the most widely proposed interlayer signaling architecture. Each protocol layer is extended with a tiny interface allowing exchange of information and configuration commands to/from the layer. These interfaces are interconnected with a cognitive engine using a common bus.

Implementation of this signaling method could be as simple as a shared database accessed by all the layers [7], while more advanced implementations introduce signaling interfaces as each protocol level internally providing an access to the internal protocol layer parameters and functions [8].

Central cognitive plane is used when optimization process involves availability of information and performing actions at more than two layers simultaneously. This way, a central point assesses values of internal protocol layer parameters via interlayer interfaces, makes an optimization decision, and communicates a set of actions that need to be performed back to the layers.

B. Network-level Signaling

Most of the existing cross-layer signaling proposals employ signaling between different layers within the protocol stack of a single node. However, as emphasized in [9], true cognitive networking should maintain a network-wide scope - with the cognitive process operating on end-to-end goals. Consequentially, cognitive networks require signaling approaches capable of signaling information delivery between different nodes in the network in an effective way.

Packet headers can be used for propagation of signaling information between different nodes of the network. Nowadays, many protocol headers of TCP/IP family, like TCP or IPv6, are extended with optional fields. Signaling information transmitted in these optional fields propagates along the packet flow and can be assessed at every router as well as end nodes. Such signaling methods keeps overhead at the minimum while allows signaling information be associated with a particular network packet. On the other hand, disadvantage of signaling using packet headers is in the limitation of signaling direction to the packet flow. However, this drawback can be resolved with the use of ICMP messages for signaling.

ICMP messages constitute the default signaling method from the early days in networking. Signaling information, encapsulated into ICMP and IP headers, can be directed and processed by the destination in the way ordinary IP data packets are routed in the network. Moreover, with a few exceptions ICMP messages are processed at the protocol stack kernel level rather than in the user application domain.

Signaling using ICMP messages is desirable when instant communication should be performed out of the regular data flow direction. In order to maintain association of signaling information with a particular packet an explicit reference to this packet should be included. ICMP messages consume network bandwidth and influence delay resources of other flows corresponding to a heavy overhead solution. Thus, they should be used as a complimentary signaling scheme to packet header.
Explicit Notification schemes, like Explicit Congestion Notification (ECN) presented in [10], is another example of network-level signaling. ECN signaling is performed in-band by letting network routers to mark in-transit TCP data packets with a congestion notification bit. Then, at the received this marking is turned back in TCP acknowledgement directed to the sender node.

The main advantage of explicit notification schemes is a low overhead. The drawbacks are in the limitation of signaling propagation to the data packet paths, requirement for maintaining signaling loop through the receiver, as well as requirement of all network routers to support signaling and traffic generation functionalities. Comparison and Relevance for Cognitive Networks.

In this section we compare available signaling approaches by the comparison of their individual characteristics like type of signaling, scope, signaling latency, communication overhead, in-band or out-of-band type of signaling, direction of signaling and whether signaling information can be associated with a particular packet flowing in the network.

It appears there is no optimal choice of signaling scheme performing well both for node- and network-level signaling in all the considered scenarios. For that reason, several signaling methods should be employed in cognitive networks at the same time to ensure efficient functionality of cognitive algorithms.

The following characteristics are relevant when considering the choice of signaling method.

Scope defines the boundaries of signaling method operation. Solutions limiting their operation to a single protocol stack tend to be more flexible in the choice of signaling techniques: they can use internal protocol stack techniques such as packet structures or callback functions, thus avoiding processing related overhead and the need for standardization effort.

Solutions operating at the node are suited for signaling between reconfigurable elements of cognitive network injected inside the protocol layers. In case only several protocol layers are concerned by a cognitive network implementation signaling is typically performed using direct interlayer communication methods. However, in case of many protocol layers concerned, either interlayer signaling pipe or central cognitive plane are the desired solutions.

Type of signaling corresponds to the communication primitives supported by each signaling method. Approaches encapsulating signaling information into packet structures, like interlayer signaling pipe, packet headers, and explicit notification, are limited to indication primitive. While other approaches performing out-of-band signaling transmissions can perform wider range of communication types including request-response actions.

According to the type of signaling the choice of appropriate approaches depends on the actions required to be performed between cognitive agents. At the node level, cognitive engine performing blind monitoring of the environment can be connected with the cognitive engine core using methods supporting indication primitive only. This will allow low-overhead communications. However, in case a cognitive agent should follow setup comments request-response actions become unavoidable requiring the use of heavier signaling approaches.

In-band / Out-of-band parameter shows whether existing data traffic flow is used as carrier for signaling information (in-band) or signaling information is sent on its own (out-of-band). In-band signaling methods do not add any significant overhead in term of network bandwidth and routing resources. However, the main drawback of in-band signaling, like packet headers or explicit notification, is in type of signaling limited to indication primitive only and relatively high latency of message delivery. On the other hand, out-of-band signaling is not constrained in signaling type and allows the fastest information delivery between ends. However, this is done at expense of network resources.

Direction of signaling is an important characteristic which defines the applicability of the signaling approach to the chosen cross-layer optimization scheme. The out-of-band signaling schemes are packet path independent and can provide a faster reaction to an event. This reaction can be preformed also in synchronous way, while packet path dependant signaling provides only asynchronous reaction. The speed and flexibility of path independent signaling comes at the expense of the additional communication resources. Nevertheless, path independence cannot be only considered as an advantage as it does not allow packet association.

Packet association shows whether signaling information can be associated with a specific packet transmitted through the network. Such property is required by many optimization approaches. For example, at the network level ECN signal sent along with a TCP data packet and echoed back with TCP acknowledgement by the receiver indirectly carries information related to TCP flow for which ECN signal is sent. At the node level information monitored at the physical layer (SNR or BER) is typically required to be associated with a packet it was measured for.

In-band signaling techniques maintain indirect association with between transferred signaling information and the packet used to carry it. On the other hand, if out-of-band signaling is used such association can be inserted explicitly. A good example is when “Time Exceeded” ICMP message sent by a router for a packet dropped due to expired TTL includes the copies of protocol headers of the packet dropped.

CONCLUSION

Cognitive Networking tries to redefine traditional statically configured networking into a dynamic, adaptive and intelligent networking. Changing whole Internet to be fully cognitive is a challenging task, because current hardware is not designed to be software programmable. Before there are standards for software defined networking equipment it is unlikely to Cognitive Networking to appear outside research labs. It is likely that cognitive technologies appear first in the mobile and especially cellular networks, because wireless technologies urgently need more capacity and current statically assigned radio frequencies makes it difficult to increase traffic in wireless space. In future the old government controlled radio spectrum allocation scheme could be transformed into a dynamic cognitive allocation of whole radio spectrum, where most of the spectrum is allocated on demand. One of the main disadvantages of Cognitive Networking is the added complexity, which directly increases cost of networking equipment. Therefore it is likely that wired networking would not be cognitive in the near future.

Software defined networking could provide better ground for cognitive networking, if the technology gets accepted Internet-wide. Seeing how slow progress it is to change Internet from old ipv4-protocol to new ipv6-protocol, it might take a long time until cognitive networking gets accepted as standard for Internet.

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