Cognitive networks

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***Abstract*—Current computer network technology is statically configured and it can not 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. In this paper we analyze different aspects required to make networks truly cognitive and efficient.**

I. Introduction

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 can not 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.

There are multiple research questions how to make networking cognitive. One target is traditional TCP/IP protocol stack, which simplifies transfers by isolating layers from each other. This contradicts thinking of cognitive networking, which aims to be aware of state of everything in every level of network. One goal is to augment current stack with cognitive capabilities. Another question is how to predict what is going to happen in network soon. Game theoretic and artificial intelligent methods are best candidates for achieving this goal. Third related question is how to utilize current radio frequencies better for mobile data communication. Currently data communication has fixed frequencies for use, while at same time there are lot more frequencies reserved for low traffic uses. Cognitive radio tries to take these low traffic frequencies in use by listening which frequencies are not sending anything and loan that bandwidth for a short period of time. Single cognitive radio does not have same end-to-end scope as cognitive networking. When multiple cognitive radios are grouped together in cognitive radio network, it can operate as a part of cognitive network. Cognitive radio is proposed to be included in fifth generation mobile wireless standard (5G) [5].

Structure of this article: Chapter II discusses gives detailed description of cognitive networking and problems it tries to solve. Chapter III gives more detail about framework for Cognitive Networking. Chapter IV includes some design issues for Cognitive Networking. Chapter V discusses findings in the paper.

II. What is a Cognitive Network

Cognitive network is a data communication network, which consist of intelligent devices. Intelligence means that they are aware of everything happening inside the device and in the network they are connected to. Using this awareness they can adjust their operation to match current and near future network conditions. Cognitive Network aims to be proactive, so that it can predict most of the usual use cases before they occur and adapt to those beforehand. If predictions fail it falls back to reactive method and tries to solve optimal way of handling the new situation. In any case Cognitive Network learns from every situation it encounters and uses that information for future cases. Main goal of Cognitive Network is to increase network efficiency and performance. Important aspect of cognitive network is that it optimizes data communication for whole network between the sender and the receiver to meet required end-to-end goals of users of the network.

Network becomes cognitive when all the statically configured parts of network are replaced with self-adjusting and self-aware components. Statically configured nodes are not cognitive, because they need an external operator (human) to make decisions and take care of configuration. Promise of cognitive networking is that network itself can find optimal ways of connecting devices and tuning network parameters to achieve best performance for data transfers. It can even optimize for events that are not happened, but are likely to happen. Conventional network forwards packets using routing algorithms and detect failures after packets are lost. Cognitive network knows status of every node, so it doesn't send data

using a route that can not deliver the packet and so it prevents congestion.

There have been multiple definitions of cognitive networking each one refining the definition tighter. Thomas et. Al [2] defines CN as: *A cog nitive network is a network with a cognitive process that can perceive current network conditions, and then plan, decide, and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account end-to-end goals.*

Li et. al [4] defines CN as: *A cognitive network is an intelligent network consisting of a programmable network and a cognition plane. The cognition plane gathers network conditions, reasons, learns, makes judgment, and adapts the programmable network based on network-wide goals.* Cognition plane is currently best candidate for making network nodes aware of the status of the network, so it is justified to include in the definition itself. Programmable network can be adjusted with software. It uses sensors to collect network information and forward the information to the cognition plane. Inside every node protocol layers have tiny interface with cognition plane to feed the sensor data into it. Cognition plane gathers network conditions, makes analysis and decisions how to adapt the network. Actuators are used to reprogram the network using the decisions by cognition plane.

Cognitive network includes all types of communication networks. Most research has been done around the wireless technologies, because wired networks are not limited in bandwidth like the radio networks are and best performance gains are expected from cognitive radio networks. Cognitive radio networks are needed because current scheme for assigning fixed radio frequencies for wireless networks results in congestion in high traffic bands and under-utilization in most of the bands.

A. Related technologies

While Cognitive Network has much in common with Cognitive Radio and Cross-layer designs, there are lots of differences as well. Cognitive Radio is only considering scope of single radio and tries to optimize conditions for single user only. Cognitive network is trying to optimize whole network to gain best end-to-end performance. When cognitive radios are combined in Cognitive Radio Network, they can optimize their usage taking account other users at same time.

Cross-layer shares similarities with Cognitive Network in breaking traditional layering and sharing information with external observer and adjusting its behavior to current sessions needs. Cross-layer is described as a single objective, meaning that it can not adapt to multiple goals efficiently. Cross-layer does not learn from past, so it repeats same behavior when provided with same input, even the operation would be very inefficient.

Software Defined Networks [6] and software defined radios are both closely related Cognitive Networks, while they don't necessarily have any intelligent components. Cognitive networks and Cognitive Radio networks depends on both of these technologies, because they enable network to adapt dynamically without user intervention.

III. Components of cognitive network.

Thomas et. Al [2] describes cognitive network with three layer framework. At top level there are applications, which have their own end-to-end goals described in Cognition Specification Language. The bottom layer is the Software Adaptable Network, which is the physical layer with sensors monitoring the network environment. The middle layer is the Cognitive Process layer, which makes decisions based on goals from application layer and network status from physical layer. Decision making must balance between different end-to-end goals, information gathered from past sessions and current sensor information and predict which kind of adjustments would be optimal to meet the goals as good as possible. Decision making relies on Artificial Intelligence technologies and can incorporate many different solutions for different situations.

IV. Design issues

There are multiple design issues involved with cognitive networks. Current network technology is designed to hide details what is happening inside network, but cognitive networking must be aware of everything. Cognition plane is designed to give access to all internal data of network and using the plane network gets necessary information from all cognitive nodes and is able to make adjustments. Communicating status between nodes is second issue, because too much overhead from signaling consumes all the performance gains of CN. Different signaling methods have been compared in [3]. Network has to store history information what happens in the network into a database and predict future events using the database and current network conditions. Predicting future involves machine learning technologies. Hardest design issue is how to make cognitive network designs cost effective and efficient. If cognitive networking adds too much complexity, cognitive networking hardware will be too expensive.

V. 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 are urgently needing 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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