Networking of Information for Cyber Physical Systems

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***Abstract*—Planet scale growth in deployment of mobile and interconnected devices interacting in a participatory sensing, collection and dissemination of information, have motivated interest in Cyber Physical Systems and the Internet of Things. Therefore, the problem of information overload and big data becomes inherent. In this project, we introduce the concept of Information topology and propose a networking paradigm that can cope with the requirement of services and applications dealing with the massive amount of information. In this work we make a proposition on the networking paradigm of cloud as a key enabler of M2M communication. The second part of our work focuses on a novel approach to dissemination of information aiming at a lower processing overhead towards an energy efficient method for networking of information in larger systems. We consider a content-centric networking paradigm that is aimed at enhancing the dissemination of information and eliminating many problems of host based communication. The proposed method is based on a network coding approach which leverages the spectral characteristics of network topology. We argue that topology of interacting nodes within a cluster can influence the performance of network coding from a computational complexity perspective and therefore the overall energy consumption in a system. We propose an algorithm that takes an opportunistic strategy to utilize the social structure and spectral characteristics of the network topology based on our design of a multicast coding network that reduces the number of encoding nodes.**

I. Introduction

The emergence of cloud computing and rapid increase in creation and dissemination of information over the Internet, evolved the society to consider the Internet as a source of information and services that is delivered to them by the network. Cloud computing is one of the key enablers of cloud services and cyber physical systems at large. It promotes the delivery of computing as a service rather than a product. In this paradigm, shared resources, software, and information are provided to computers and other devices as a utility in a manner that do not require end-user knowledge of the physical location and configuration of the system that delivers the services. The future internet is facing the problem of information overload and the existing networking solutions may not be able to cope with the rapid increase in the amount of information available. Cyber physical systems and ubiquity of sensors, devices, and embedded systems has lead to the transition towards the networking of information as opposed to networking of devices. This calls for a transition from an end-to-end communication paradigm to a content-based networking paradigm. The potential of this shift in the Internet architecture could be significant, since it impacts both the communication model and the network infrastructure. Content-centric networking enables a dissemination platform and is one of the success enablers of mobile clouds that addresses the problems of intermittent connectivity and leads to a more intelligent communication. Content-centric networking is about shifting from the end-to-end communication towards a network of information, decoupling location from identity, security, and access. In this paper we argue that future cloud services will benefit from this shift in communication paradigm and demonstrate our perspective of a content delivery platform for future internet that is based on the service oriented architecture design principles. Network coding is a general case of routing. In network coding approach, a linear combination of received packets are transmitted at the egress while routing only performs a forwarding with no arithmetic operations performed. Inherent multipath support in a content-centric networking paradigm makes network coding a suitable approach.

II. Proposed Method

The key ingredient of our approach is leveraging the spectral characteristics [**?**] of network for selecting the key player nodes for performing network coding. Specifically, we show that in the networks with good expansion properties, our decentralized approach yields a better reliability and less computational cost. The motivation behind the proposed method is that with a content-centric networking architecture, network coding can be deployed for a better utilization of redundant capacity. On the other hand, information about the spectral characteristics of chosen clusters can be utilized for a more efficient data dissemination based on social interaction and connectivity of participating nodes. The results presented in [1] argue that linear coding with finite base field suffices to achieve the Max-flow Min-cut bound for multicast.

In our proposed method, selected nodes within the network will perform network coding and these nodes shall form a topology that constitute a good expander. The procedure

Algorithm 1 Cluster Selection Based on Spectral Characteristics

Require: $C \in G = (V, E)$
Ensure: There is a network coding solution for the network
$C = G$
Calculate the initial $\eta(C)$
for $\forall v_i \in G = (V, E)$ **do**
  while C is connected **do**
    if $\Delta(v_i) \leq k$ **then**
      Remove v_i and update C_i
    end if
  end while
end for
$C \leftarrow C_i$
Construct the expander $X = (C, E')$

for selecting such subset is shown in Algorithm 1. In this algorithm, the result is an expander of constant degree no less than k.

A. Networking of Information in Cloud

With the fast growth in cloud computing and transitioning of network infrastructures into cloud, one can realize that a content-centric approach to networking is a suitable approach towards efficient deployment of cloud. The scalability characteristics that cloud services can offer, makes it feasible to implement the network elements in the cloud. While SOA is part of the already existing web services solutions, the web services still suffer from constraints of interface. Web services should be interacted and interfaced via internet protocols such as HTTP, FTP and SMTP. CCN can be the motivator that utilizes the cloud beyond data centre into routing centres and that would be the matter of optimizing the cloud for a content-centric approach on content delivery or delivery of highly interactive applications where latency is an issue specially in the case of mobile networks.

B. Content Distribution Efficiency

The efficiency of content dissemination in CCN arises with the situation of larger number receivers and sink nodes. The experiment done in [2] has shown that TCP scales linearly with increasing the number of sink nodes while CCN follows a constant scale. Since TCP traffic is per connection, as the number of connections increase, download completion time gets larger. However, in the CCN approach, the traffic would cross the path only once. As discussed and evaluated in [2], it is important to consider that although the performance penalty of using CCN due to its packet overhead vs. TCP is around 20%, the performance gain for the case of larger sink nodes is integer multiples.

C. Coupling and granularity

The design of cloud services and applications are currently tightly coupled to the underlying access network and internet protocols such as HTTP, SMTP, and FTP. Although the virtualization has aimed at improving this, it is more advantageous to have a clean slate design to tackle the scalability problem and addressing the issues arising from dynamics of networks. Large dependency among services and entities within a system degrades the granularity of that system. Cloud-based internet architecture is currently tightly coupled with the issues relating to connectivity. It is therefore important to decouple the connectivity from applications and web services. Coupling and dependency factor scales linearly with the number of attributes that relate the entities. CCN paradigm of networking aims at decoupling the content from the location where the content is stored, making the design of services and applications IP agnostic.

D. Stateless Design

Service statelessness is one of the important design considerations for services composition and management. In essence, statelessness supports scalability. Statelessness results in reduction of the resource consumption by a service or an entity as the state management is migrated to an external component within the framework. By reducing network resource consumption, the underlying network can handle more requests in a reliable manner. Another issue due to statefullness is the negative impact on performance. For instance, multimedia web services that are currently tightly coupled with the internet protocols such as RTP, HTTP, and etc, can face disruptions and QoS degradation if there is intermittent connectivity issue. In a content oriented approach of networking the state of underlying connection is abstracted from the content layer. Strategy layer of CCN manages the active interfaces and hides the complexity and state of topology from content layer. The rationale behind this argument is to make the interested entities decoupled from dynamics of unstable entities.

III. Conclusion

In this paper we raised the problem of information overload in cyber physical systems and provisioning of applications and services of the future internet. Cyber physical systems constitute a large system with a large amount of participating nodes. CCN paradigm implies that the intermediate nodes are content-aware. We proposed an algorithm based on an enhanced network coding scheme that leverage the spectral characteristics of the network topology to minimize the number encoding within the system and reducing the computational cost.

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