# Dynamically Adaptive Networks and provision of flexible services: Dynamically self-organized communities for content distribution and resource sharing

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**Abstract.** The work described in this thesis targets the introduction of an architecture in order to combine the two alternative models, and also exploit self-organization features of future networks between nodes of close proximity. The participating nodes form loosely coupled communities that enhance node cooperation for increased content distribution efficiency. Each node first searches for content to his peer members within the community, and if this cannot be satisfied the node resorts to the use of the infrastructure network. The provisioning of local content on each node is reciprocated with additional external bandwidth by the network gateway. The node cooperation is enforced by specific incentives that facilitate the node collaboration and deterrent measures that inhibit misbehaving nodes. In this work, the introduced architecture considers initially a centralized approach, then a distributed approach, and finally it is mapped to a SDN and mobile cloud enabled solution. The decision making mechanisms considered for the self-organization of the nodes is based on a theoretical model using game theory. Finally, simulation results for the proposed approach are presented to demonstrate the performance gains.

## 1 Introduction

In today's networks the content distribution landscape is changing. The evolution of mobile end user devices, with increasing processing, memory, storage, and display capabilities is changing the approaches for content placement[4], [5], [6]. Content is not restraint only to centralized storage servers but is also migrated towards end user devices, where it is transported and shared[1]. Furthermore, we experience a proliferation in user generated content, driven again by the evolution of end user devices. There is a diffusion among content producers, distributors and consumers. Users can operate on any of these roles. For the distribution of the increasing content volume, the two main approaches are the use of peer

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to peer networks and social networks. Peer to peer content distribution is used for high volume content transfers, usually in the case of high quality content. Besides the traditional bulk transfer mode, peer-to-peer streaming services are also becoming popular to provide on demand content to the members. On the other hand, social networks have become perhaps the most prominent means of content distribution. People use social networks, not only to keep in touch with friends and acquaintances but also to stay informed on news and events. Furthermore, people form groups of similar interests to exchange information and ideas. Most of today's web traffic is created by the use of social networks. This has a big impact on the network to provide the communication infrastructure and respective services for supporting the increasing volume of traffic for content distribution.

Both of the two predominant Internet application architectures (i.e., client-server and peer-to-peer (p2p)) essentially assume that nodes operate in isolation, even when close proximity exists. There are many cases where one user wants to retrieve or share information or content (even in real time) with other nearby users, but the communication has to take place over centralized services through the Internet. The work described in this thesis targets the introduction of an architecture in order to combine the two alternative models, and also exploit self-organization features of future networks between nodes of close proximity. The participating nodes form loosely coupled communities that enhance node cooperation for increased content distribution efficiency. Each node first searches for content to his peer members within the community, and if this cannot be satisfied the node resorts to the use of the infrastructure network. The provisioning of local content on each node is reciprocated with additional external bandwidth by the network gateway. The node cooperation is enforced by specific incentives that facilitate the node collaboration and deterrent measures that inhibit misbehaving nodes. In this work, the introduced architecture considers initially a centralized approach, then a distributed approach, and finally it is mapped to a SDN and mobile cloud enabled solution. The decision making mechanisms considered for the self organization of the nodes is based on a theoretical model using game theory. Finally, simulation results for the proposed approach are presented to demonstrate the performance gains.

The main outcomes of the work is in future networks we expect to have big gains in overall network resource usage by reducing the traffic to the main network infrastructure when exploiting the proximity and collaboration of nodes. Moreover, there is also gain on the node side in terms of delay in content acquisition.

## 2 Dissertation summary

This dissertation presents in details the proposed architecture, and the network protocol to implement. The architecture is originally developed using a centralized approach, then a distributed approach and finally a solution based on Software Defined Networking (SDN) and mobile cloud. The internal architecture of

communities follows a flat structure using two main entities: participating nodes and the leader of the community. Furthermore, for the mechanisms implementation the assistance of network gateway and the mobile cloud infrastructure, in latest case, are required. The nodes participate in the content distribution, either as providers or consumers or intermediaries, vote in the voting process for other nodes that cooperated, report misbehaving nodes and finally can claim better service quality from the network gateway if they have acquired sufficient number of votes. Furthermore they offer a piece of their memory in order to create a global memory of the community, which may be used by other nodes as temporary storage. The leader of the community manages the community, collects votes, allocates additional bandwidth to nodes and advertises the community in order to enroll new nodes. The network gateway manages the bandwidth used to connect to the Internet and distributes it to the nodes according to the instructions of the community leaders. This is achieved by reserving a percentage of the total outgoing bandwidth and has offers it to the community leaders to distribute it to their members.

In the centralized approach the role of the community leader is undertaken by the network gateway. The network gateway is responsible for the construction, community operation and the bandwidth sharing. The network gateway initially builds the community by asking local nodes to the tags and size of content they already have or tags that interests them. Then it starts advertising the community to new nodes entering the region. The advertisement includes the community identifier, community tags. Furthermore it includes the size of the content size for each tag and the memory that the new node must offer to enter the community. After the mutual agreement the new node enters the community, and he participates in the content distribution, where for each file that he retrieves through the community he returns a proof the provider node. This proof is the vote used during the voting process, as presented and the corresponding vote counting algorithm. Finally, the reporting mechanism and additional functions of community as the content advertisement of the nodes are described. For the theoretical study of cooperation incentives, game theory was used. The nodes throughout this thesis are considered to behave selfishly, but rationally. Each node attempts to maximize his profit, but will not take an action that would be against his interest. Two games are described: the admission of a new member in the community, and the nodes' cooperation within the community. In the new node admission is shown that through the advertisement values of the community and the corresponding supply of the node, the cooperation is the most effective strategy only if and both sides believe that they will benefit. In this way community leader makes an initial filtering to the community members without allowing the admission of nodes who do not offer, while the nodes do not participate in a community that they offer too much. In the cooperation game it is proven that as the nodes try have better quality of service to the Internet, the best strategy is to collaborate with the other members.

The main drawback of the centralized approach are the number of changes that have to be made on the network gateway. Moreover, the functioning of

communities is not as autonomous, since an external entity is participating in the internal community operations. Furthermore, from the description the centralized approach, there is one community that strives to meet the needs of the majority of the nodes in the region. It would be easy to extend this so that the network gateway supports more than one community, but this would lead to an increase of the complexity on the gateway itself. Therefore the distributed approach is proposed[3]. The role of the community leader is undertaken by a community member. In this way more than one community can coexist in an area and a node can participate in more than one. The network gateway distributes the reserved bandwidth to the communities depending on the size of each community and guarantees that nodes have the additional bandwidth that their have gained. In the distributed approach, because the leader community is a node with limited resources, it is necessary to create safeguards in cases where there is either voluntary withdrawal or failure of this node. Finally, the protocol is extended to include communication of community leader with the network gateway for the bandwidth allocation. The assumption that the community in centralized approach is fair (the portal has no profit by acting unfairly) does not apply in the distributed approach, as the leader may take advantage of the extra bandwidth for his own exclusive use. This phenomenon is studied using game theory. In the distributed approach, the node model is extended and a separation of the nodes is introduced in nodes looking for more bandwidth compared to nodes seeking more content. The game between the community leader and participating nodes participants shows that if the leader it is not fair to the members, they cooperation among the members breaks, members leave the community and the community shrinks till it stops existing.

The distributed approach requires from the community leader to consume resources for it's operation, forcing consequently only a certain class of nodes to play this role and for small time periods. To solve this issue an approach that is based on the use of SDN mobile cloud is used[2]. In this approach, the role of leader remains in the members of community, but moreover resources are committed centrally from the cloud infrastructure, which they undertake the demanding community operation. The auxiliary resources undertake the community's control plane , while the management plane and final decisions remain in the community leader. There are essential changes in the protocol for the offloading of operations in the auxiliary infrastructure. Based om this approach, the study of the community advertised values is presented and it is proved that for smooth and fair operation of community the optimal solution is the use of means values within the community. Finally, the behavior of the leader regarding the advertised prices is studied. The leader can select to advertise bigger or smaller values than the average. In any case via the game presented that is played between the community leader and the members of his community, it is proved that the advertisement of false values leads to the shrinkage of community.

## 3 Results

The evaluation of the architecture is based on two axes: the viability of the communities, and a analysis of optimization that can be achieved For the viability two simulations were executed. The first simulation studied the size of the community, of the community content and the global memory. For the modeling the games described in the architecture presentation were used. The results shown in figure 1 show that the size of community increases, while at the same time the total content and the global memory also increase linearly with size of community. Consequently, using this architecture homogeneous communities are created, in which there are no nodes that offer in excess or nodes that don't offer back. The second simulation for the viability shows what happens in the case that a community leader is not fair to the rest of the members. Two cases were simulated. In the first case two communities existed with fair leaders. In second case in one community the leader was fair, while in the other unfair. As it is shown in figures 2 and 3 in the first case the communities continued keeping or slightly increasing the number of their nodes. On the contrary, in the second case the community with the unfair leader a mass departure of nodes took place after some time resulting to the extinction of the community. This simulation strengthens the results that were presented in the game theoretic study.

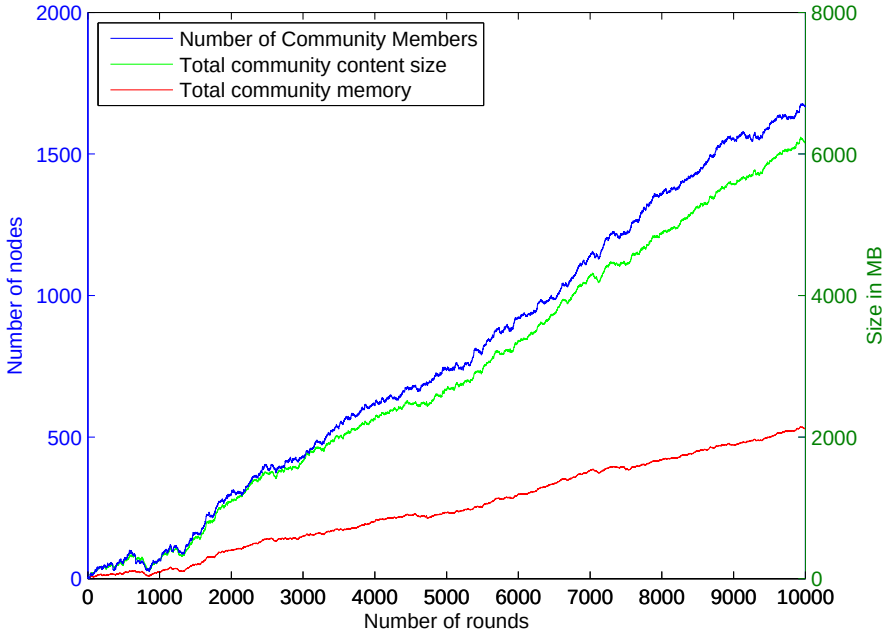



**Fig. 1.** Number of nodes per round

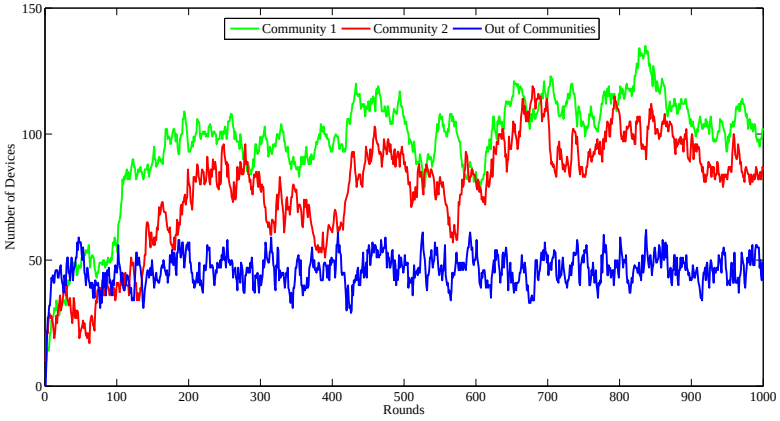



**Fig. 2.** Number of nodes in communities with fair leaders

For the evaluation of the optimization that is achieved with this architecture two simulations were performed. The first analyzed the reduction of the external network load due to the content distribution inside the community. We simulated a number of nodes that made constant requests to the network gateway to acquire content. Without the use of the architecture all the requests have to be serviced by the network gateway, while with the use of the community a number of requests where served by the nodes. The results shown in figure 4 show a reduction of external requests raging from 20 %, if the file choice was made using a uniform distribution, up to 400 % , if the file choice was made using a zipf distribution. In the second simulation we studied the optimization in content distribution inside the community. We compared per time needed to download a number of files using the Bittorrent protocol with and without the existence of the community architecture. The number of community members, as well as the mobility range of the nodes was varied. The results depicted in figure 5 show that in small mobility range of nodes the use of community has marginal benefits, but as long as the range grows then the benefits increase dramatically reaching improvement of 90 %. The results show that there are concrete benefits also in the end user content distribution.

## 4 Conclusions and future work

The overall conclusions of the thesis are that the presented architecture can offer benefits in the network infrastructure by reducing the load on the external connections. Moreover there are benefits on the user side by offering better content distribution. These benefits stem from the cooperation of nodes that are in close proximity. Future extensions of this work can be made in various axes. The first axis is the thorough study of user behavior within the communities in order to

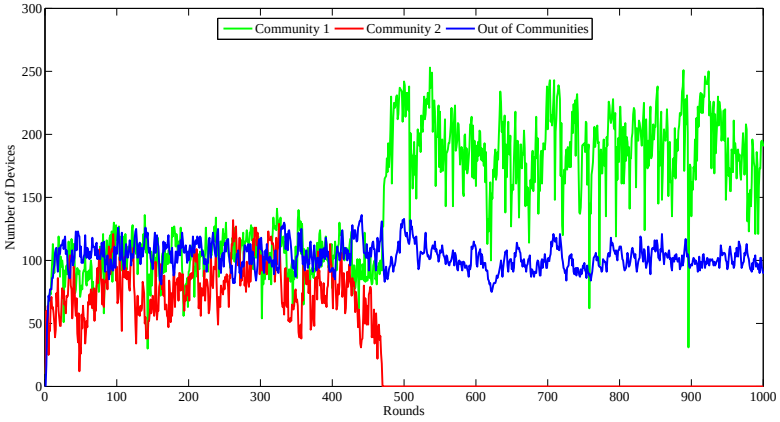
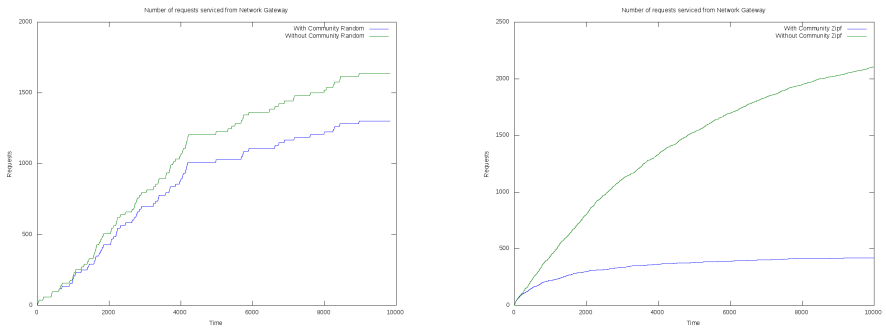



**Fig. 3.** Number of nodes in communities with fair and unfair leader




(a) Random (b) Zipf

**Fig. 4.** Number of requests through gateway with and without the community (20 nodes)

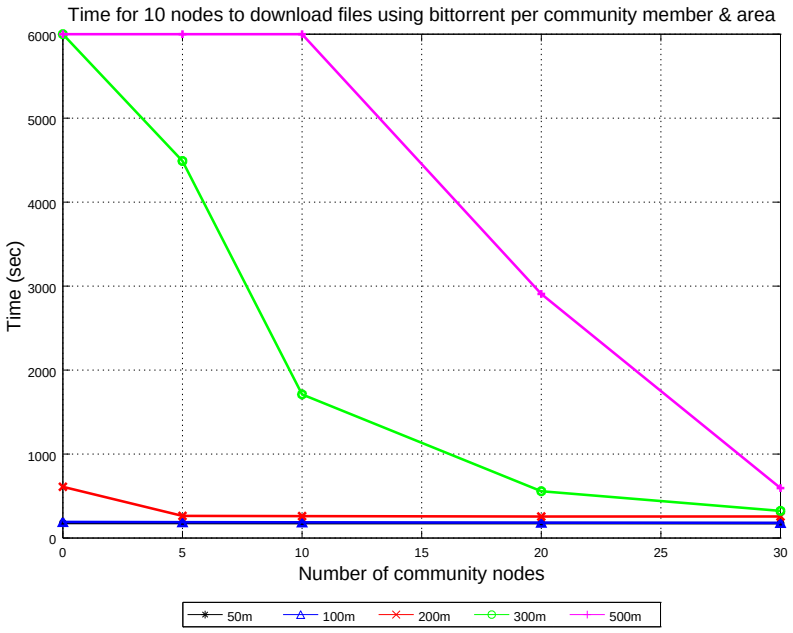



**Fig. 5.** Aggregation of time to complete download of files per number of community members and area (10 downloading nodes, 9 files)

maximize their gains by selecting content that can be exchanged for better network service. Furthermore, the content replacement policies when user devices fill up, should be augmented to accommodate not only the frequency of use by the user, but also the value of the content within the community. The second axis is the study of closed coupled communities that can offer better orchestration of operations. In this case mechanisms should be used that guarantee stricter commitment from the members, making possible the better orchestration of content distribution. Finally, the third axis is the generalization of architecture beyond content distribution and extend it in order to make possible more resources like CPU cycles. In this case a need for a digital currency (like Bitcoin) is required to provide the common ground for the resource exchange to take place.

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