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Towards Transitions between Role Assignment Schemes: Enabling Adaptive Offloading in Challenged Networks

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ABSTRACT

The ever increasing number of mobile devices and their heterogeneity requires an efficient utilization of the cellular communication infrastructure. To this end, different offloading approaches have been proposed in the literature. All approaches rely on schemes that assign roles to mobile users, with the respective assignment procedure being realized either centrally or distributed. However, current role assignment schemes are limited to a specific utility function by design (e.g., minimizing the energy consumption), and are unable to adapt to dynamic network conditions and target utilities. This substantially limits the applicability of offloading approaches in dynamic and challenged networks. In this paper, we propose the execution of transitions between role assignment schemes to adapt offloading approaches to challenged networks. We propose and discuss a framework that enables the integration of centralized and decentralized role assignment schemes and the execution of transitions between the respective schemes. Based on an initial evaluation of the coordination aspects of our framework, we identify future research directions and challenges towards the adaptive utilization of offloading schemes in challenged networks.

CCS CONCEPTS

•**Networks** →*Network management;* •**Human-centered computing** →*Mobile computing; Ubiquitous and mobile computing systems and tools; Mobile devices;* •**Computer systems organization** →*Client-server architectures; Peer-to-peer architectures;*

1 INTRODUCTION

Mobile networks experience massive growth not only regarding mobile traffic. An ever increasing number of heterogeneous network participants such as smart devices carried by humans and additional sensors in the Internet of Things (IoT) leads to increased cellular traffic. Additionally, devices become increasingly interconnected to enable context-sensitive applications and services, further increasing the load on the communication infrastructure. The load characteristics are subject to fluctuations throughout the day, caused by the nature of human interaction and mobility. These fluctuations are further intensified by planned or spontaneous events that affect client mobility and interaction with the respective application. The resulting load can easily exceed the available cellular capacity, especially in cases where the events are spontaneous. If application usage is limited or not possible at all as a consequence of these fluctuations, the user satisfaction is severely degraded [23].

To counteract the fluctuations, the available cellular network capacity has to be utilized efficiently. To this end, various offloading strategies have been proposed in the literature [18]. These strategies utilize other communication channels (e.g., Wi-Fi access points or femtocells) or direct local communication among devices to reduce the load on the cellular network [9, 15]. The core concept of offloading is the selection and clustering of nodes – the *role assignment* – that forward and distribute data on behalf of adjacent nodes. The selected subset of nodes then communicates with the cloud or edge infrastructure, while the remaining nodes offload their data to those selected nodes, significantly reducing the load on the mobile network. However, current offloading approaches are limited to specific target utilities (e.g., maximizing the throughout or minimizing the overall energy consumption) and address specific network conditions (e.g., specific mobility characteristics or availability of cellular connectivity on all devices) [1, 14]. Therefore, their applicability is limited in the dynamic and heterogeneous conditions that are inherent to today's mobile applications and services.

To enable the utilization of offloading techniques in challenged networks, we propose the execution of transitions between different role assignment schemes. In this paper, we present a framework that adapts the offloading process to dynamic conditions by switching between different role assignment schemes. We discuss the integration of both, centralized and decentralized role assignment schemes, as well as the execution of transitions between different realizations of the respective schemes.

The remainder of this paper is structured as follows: The scenario considered in our work is further detailed in Section 2. Section 3 presents related work in the area of role assignment approaches and offloading in dynamic mobile networks. Section 4 provides a detailed discussion of the proposed transition-enabled role assignment

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framework. Initial evaluation results regarding the coordination of transitions within the framework are presented and discussed in Section 5. Section 6 concludes this paper.

2 SCENARIO

The scenario considered in this paper describes an urban area which is subject to high dynamics regarding (i) the user density and (ii) the predominant connectivity characteristics. Furthermore, (iii) social ties between users result in dynamic formation of crowds of different dimensions over time. The user density dynamics in the urban scenario and the network are represented by nodes switching on/off their mobile devices, i.e. respective communication interfaces, or by joining or leaving the considered urban area. The resource constrained and battery powered mobile devices are equipped with communication means for local communication, such as WiFi and Bluetooth, and with a cellular network communication interface. With an increasing number of cellular network connections it is assumed that the cellular network quality is decreasing significantly [23]. User crowds form around social attractive public places, such as parks, bars or restaurants that emit a social force pulling the users towards them [8, 19]. Different strengths of social forces of public places lead to more or less crowd formations [21].

In the urban scenario people are able to walk (i) over streets, (ii) in pedestrian zones, and (iii) over paths in parks and forests. Obstacles such as walls, buildings, or rivers are taken into account and are unaccessible for the mobile nodes. Beside a multitude of applications and services that the users may consume with their devices, each device deploys (i) a monitoring service that captures required device and network status information and (ii) the local component of the transition-enabled role assignment framework presented in this paper (cf. Section 4). Incorporating the local component of the transition-enabled role assignment enables the situational adaptation of the used role assignment scheme to the requirements of applications and mechanisms and to the current network conditions. In the edge network the central component of the role assignment framework is located accessible via a well-defined API to interested applications and mechanisms (cf. Section 4). The local components are, of course, also accessible for interested applications and mechanisms using the API to allow for role assignment requests from any entity within the network.

3 RELATED WORK

Rebecchi et al. present a comprehensive overview of offloading approaches in [18] as well as others [2, 9]. Offloading approaches differentiate in their aimed utility. Many approaches rely on cellular offloading by using device-to-device communication from and to selected gateway nodes to collect and upload or distribute received data. In doing so the load and the number of needed cellular connections is reduced significantly – leading to improved service qualities even in challenging scenarios. However, with all these approaches the selection of the relaying nodes, i.e. the gateways, is a key factor for the success of the proposed solution [22]. Still, the approaches do only consider a fixed selection mechanism to obtain the to be used gateways and to cluster the mobile devices to the respective gateways [18]. Those fixed selection mechanisms are, as seen later in this section, build for specific conditions and significantly lack performance once network or environmental conditions change. Relying on the transition-enabled role assignment framework proposed in this work, a constant high performance of the offloading approach can be enabled as the role assignment is able to adapt on changing requirements and conditions using transitions. The transitions allow to utilize the best fitting algorithm concerning the current situation in the network.

Currently, emerging are Wi-Fi offloading techniques to (i) further reduce the load on the cellular network [18], (ii) rely on the higher bandwidth provided by Wi-Fi access points [15], and (iii) to use the natural movement behavior of humans [8, 19] and the public Wi-Fi access points spread in urban areas [16]. First approaches that take into account the multitude of offloading techniques simultaneously show a significant performance increase of the used applications compared to the normal networking behavior observed today [9, 20]. These approaches can also benefit from the adaptability of the transition-enabled role assignment framework as it provides a reliable source of gateways that can be used for offloading even in challenging network conditions.

As discussed before, the assignment of roles, often described as the selection of relaying nodes, is crucial for a good functionality of offloading approaches. The role assignment divides into mechanisms for gateway selection and clustering of nodes to those selected gateways. The in this work proposed transition-enabled role assignment framework is able to utilize the in the following presented approaches due to its modular structure and the support for both centralized and decentralized mechanisms (cf. Section 4). Existing gateway selection approaches are classified either deterministic or stochastic according to Chinara et al. and Bentaleb et al. [3, 5]. The utility of gateway selection approaches as well as the needed information to perform the selection varies strongly. While approaches like WCA [4], FWCABP [12], and CEMCA [24] combine multiple values to a weighted metric other approaches like LEACH [10], ALEACH [1], and DEEC [17] focus on energy efficiency, e.g. minimizing the overall consumed energy or equally distributing the consumed resources among nodes. Furthermore, some approaches like MobHiD from Konstantopoulos et al. [14] aim to provide robustness in terms of topological stability that is achieved with the gateway selection and the clustering. Within the domain of clustering in mobile networks the density-based DBScan [7], the partitioning k-Means [13] and grid-density based approaches like the work of de Berg et al. [6] evolved as first-choice algorithms. Each of these approaches provide superior results in the specified utility and conditions they were designed for, however once requirements change offloading approaches should still receive reliable results from the gateway selection and the clustering. Thus, other than existing static approaches [18], we argue that the possibility to adapt to changes must be enabled for role assignment approaches, which we provide relying on transitions within the proposed role assignment framework. In doing so, offloading approaches can benefit from a reliable selection of gateway nodes irrespectively of the predominant challenging network conditions. The discussed centralized and decentralized gateway selection and clustering algorithms are incorporated into the presented transition-enabled role assignment framework.

4 TRANSITION-ENABLED ROLE ASSIGNMENT FRAMEWORK

Role assignment is a crucial part of offloading, significantly affecting the usage of the offloading approach [22]. As seen in Section 3 current approaches for offloading and role assignment are limited in their applicability as they are not able to adapt on changes regarding the posed requirements or the network conditions. The transition-enabled role assignment framework, as introduced in the following, focuses on this essential characteristic. It consists of components for (i) coordination and dissemination of transition decisions and of components for (ii) centralized and decentralized role assignment as seen in Figure 1. It shows the central components on the left and client sided components on the right.

In the following, the structure of the centralized and the decentralized (cf. Sections 4.1 and 4.2) role assignments are explained. However, more details are given on the decentralized role assignment which is one of the contributions of this paper. Section 4.3 highlights the main contribution of this paper: the transition-enabling of the role assignment framework by introducing for example transition decision coordination and dissemination components. Finally, Section 4.3 gives insights into so-called self-healing actions in the potential case some mobile nodes did not received a transition decision.

4.1 Centralized Role Assignment

The role assignment process is triggered by applications or mechanisms using offloading structures. Required information, such as node neighborhoods, energy capacities, are obtained relying on a monitoring service. Once the required information are obtained from the corresponding nodes in the network the computation is triggered on the server sided component (cf. *Centralized Role Assignment* in Figure 1) resulting in a set of gateways with assigned nodes to each gateway forming the clusters. Afterwards, the result is either (i) returned to the requesting application/mechanism if it will notify the clients itself, (ii) distributed to all available nodes for an enriched information basis in the mobile network, or (iii) send to current and previous gateways as their assigned role changed. In the third distributing opportunity the information for the assignment, thus the clustering information, is omitted as this might not be relevant for all application scenarios.

For the centralized role assignment the order of the execution of the gateway selection and the clustering can be changed, as both are split and not functionally related. In combination with deterministic and stochastic gateway selection approaches this leads to six main classes: (i) SEC, (ii) D1C, (iii) DkC, (iv) SkC, (v) CD and (vi) CS. Based on prior work, in which the importance of fairness in centralized gateway selection approaches has been shown [22], the centralized role assignment has been extended as follows: (i) the classes DkC and SkC including the gateway selection algorithms LEACH [10], DEEC [17], and ALEACH [1], (ii) the notification and monitoring process as explained before, and (iii) the potential to perform transitions between the used clustering and gateway selection mechanisms to adapt on changing requirements or network conditions.

SEC describes the **s**tochastic gateway selection, with a number of gateways following an **e**xpectation value, concluded by a **c**lustering of all remaining non-gateway nodes to the drawn gateways. D1C describes a similar procedure, however gateways are chosen based on **d**eterministic functions **one** after another including the cluster formation of non-gateway nodes per round. DkC and SkC are similar to SEC and D1C, however the number of gateways is a-priory fixed to the parameter k which may be required by applications. The approaches CD and CS perform the clustering first followed by the gateway selection. Thus, the mobile nodes are initially clustered using DBScan [7], k-Means [13], or a grid-density based clustering scheme (cf. Section 3). Once the clustering process is finished, in each cluster a gateway is calculated based on a weight (**d**eterministic) or on a probabilistic function (**s**tochastic). The remaining nodes are marked as non-gateway nodes.

4.2 Decentralized Role Assignment

In challenging environments the use of the centralized role assignment might not be possible or intended due to overhead reasons requiring a distributed solution. The decentralized role assignment relies solely on ad hoc communication between the mobile devices to determine gateways and achieve the subsequent clustering of the remaining nodes. Four phases have been identified from the analysis of the related work which are used to achieve that goal.

Information collection from the surrounding nodes is performed in the first phase. This information is either based on actual collected data, thus involves local communication, or is based on estimations retrieved by for example eavesdropping the environment. In the second phase, each node calculates a probability or weight based on the input information or on the knowledge of the node itself. The algorithms used for calculation are either of probabilistic or deterministic nature as described in Section 3. Most of the algorithms consider and incorporate the suitability of a node based on the knowledge about the node itself. In the following, the probability or the weight is referred to as weight (ω_{own}). In this approach all weights are normalized to enable their comparison in the case of individual transitions between different weight computation schemes.

Any information on the weights of the nodes (n_i) are distributed for exchange in the third phase. During that process each nodes stores the received foreign weights ω_i for later comparison. The third phase is not part of stochastic approaches, as these approaches do not rely on actual sharing of the weights. In the fourth phase, the received foreign weights or a drawn random value (for stochastic approaches) are compared with the own weight of the node. Is the own weight greater than the foreign weights ($\omega_{\text{own}} > \omega_i \ \forall\ i$) a node marks itself as gateway. Once nodes decide on their own role as gateway they spread their decision in the network. Adjacent nodes, which decided to become non-gateway nodes, receive this message and cluster to the respective *best* gateway they get notified by. Additionally, mechanisms to (i) trigger (timer- or event-based) the gateway selection and to (ii) select a foreign gateway out of a list of heard gateways are used. Non-gateway nodes that are aware of more than one gateway in their proximity after the dissemination of the role assignment select their gateway either as *first heard* or as *nearest* with respect to the hop counter of the disseminated message. The selection of the gateway for non-gateway nodes is

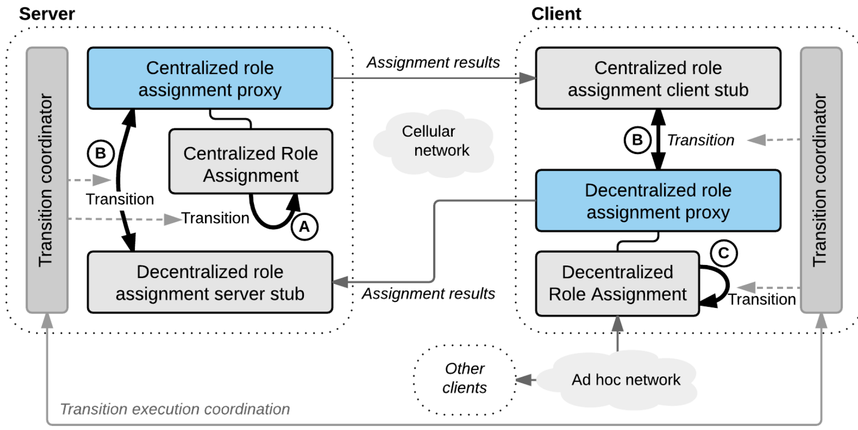


Figure 1: Server and client components of the transition-enabled role assignment framework.

described as a fifth phase when non-gateway nodes try to register at their chosen gateway.

The decentralized role assignment starts, similar to the centralized role assignment based on trigger events from e.g. applications or mechanisms. As other mechanisms might be interested in the activation of the decentralized role assignment, they can subscribe to the trigger component to be notified on the start of the role assignment procedure. For all local communications within the decentralized role assignment transition-enabled, i.e. during runtime exchangeable, local dissemination approaches are used. All dissemination schemes use a sequence number-bases duplicate detection algorithm to prevent unnecessary sending of messages. Furthermore, the algorithm assigns messages an importance value (IV_{m_i}) between zero and one. Messages that occur for the first time, are assigned the highest importance value, leading to immediate sending. Others are, depending on their importance value, only send if the individual time-to-live (TTL) of the message allows it. Currently, (i) a flooding-based, (ii) a contention-based, and (iii) a probabilistic approach are used. The flooding-based approach is used as a baseline for the second and third dissemination approach, as a simple flooding can result in broadcast storms which degrade network performance. The contention approach computes, based on node attributes such as neighborhood, load or remaining battery capacity, a contention time t_{con} in the interval $[t_{con_{min}}; t_{con_{max}}]$. If during the contention t_{con} the node overhears another adjacent node forwarding the message, it will discard the message. If no other node sending the message is overheard, the node will send the message. The contention-based approach includes in worst case longer latencies, that therefore lead to reduced freshness of the information, which may influence the obtained results negatively. Thus, a probabilistic approach can be used as well, depending on the current network situation. However, to avoid too early dropping of messages the probability to drop messages is also depending on the hop-distance from the message's originator node.

4.3 Coordination and Execution of Transitions in the Role Assignment Framework

The presented centralized and decentralized role assignment schemes (cf. Sections 4.1 and 4.2) are able to perform local transitions, thus from a centralized to a centralized scheme (cf. notion A in Figure1) and from decentralized to decentralized (cf. notion C). This improves their flexibility significantly concerning the requirements or the network conditions [22]. The transition coordinator on the server and clients coordinates transitions between both schemes, thus from centralized to decentralized and vice-versa (cf. notion B). A transition between the centralized and decentralized role assignment has greater impact on the result as both schemes work differently and comprise of different benefits and drawbacks.

In the design of the transition-enabled role assignment framework (cf. Figure 1) the coordination and the execution of transitions is separated. For the execution of transitions the framework relies proxies and stubs on the client and server component. A transition between the centralized and the decentralized scheme involves all nodes. Individual mechanism transitions instead may only affect individual nodes and do not have to be disseminated in the network. The transition from the *first heard* to the *nearest* selection of heard gateways in the decentralized role assignment (cf. Section 4.2) may be such a transition that is only relevant to a single node or a subset of nodes. Transition-enabled components are encapsulated using so called *proxies*. There is a centralized role assignment proxy located on the server, while the decentralized proxy is hosted on the clients (cf. Figure 1). The centralized role assignment has transition-proxies for the used gateway selection and clustering approach. This enables it to represent the six main classes and their multitude of implementations as explained in Section 4.1. The decentralized role assignment has also proxies for the gateway selection and the used clustering. Furthermore, it has proxies for local dissemination of weights, the weight calculation approaches and the triggers used by the nodes resulting in a flexible configuration space.

The decision to perform a transition is rule- or event-based. The coordination layer, represented by the server and client sided transition coordinators, is responsible for the distribution of transition decisions to the respective target nodes. Depending on the targeted nodes different dissemination algorithms are used by the coordination instances (cf. Figure 1). The dissemination strategies can be exchanged during runtime, to allow for adaption on the current situation. In the following we consider transitions to target all nodes in the network, as guaranteeing that all nodes in a dynamic environment are reached in a short period of time is more cumbersome than reaching only a few. To avoid misconfiguration in the network, which might occur if nodes do not overhear a transition decision a self-healing approach is used on the role assignment client and server instances. Messages of the transition-enabled role assignment framework, e.g. result distribution of the centralized role assignment or gateway notification messages in the decentralized scheme, contain a transition counter and the respective configuration of transitions that target all nodes. Relying on that counter other nodes hearing such messages can validate their state and if needed perform a local transition to the shared configuration.

Whenever transitions are performed so called *state* might be transferred. However, only supported state is transfered to the new mechanism so that it can benefit from the results of the previous running algorithm. The main state, among others, is on the client side the local role and the current local gateway. On the server the complete assignment is transfered, however this does not have to be the exact representation of the current situation. Furthermore, when configured in the decentralized scheme, trigger listeners as well as local message buffers are transfered during transitions to enable for example duplicate detection withing the local dissemination of messages of the role assignment process.

5 COORDINATION OF TRANSITIONS

The initial evaluation targets the coordination aspect of the proposed framework by (i) highlighting open research challenges regarding transition execution processes in challenged networks and (ii) comparing a subset of currently used transition decisions dissemination options in the proposed framework (cf. Section 4.3). In the following, we detail the modeling of the scenario including the used evaluation metrics and the results of the evaluation.

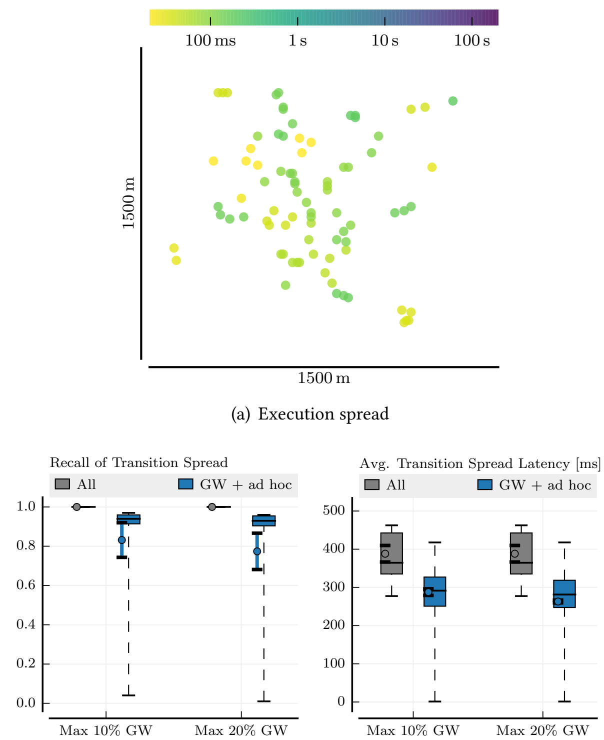
5.1 Scenario Modeling and Evaluation Setup

The Simonstrator platform [21] is used for the evaluations. It comprises the IEEE 802.11g standard from the ns-3 simulator [11] to model device-to-device communication. The urban area is modeled based on OpenStreetMap data in which nodes are able to move on streets and path. Attraction points and social ties within the used movement model lead to group formations of different sizes as explained in more detail in [21]. Two hours of operation are simulated over ten different seeds. Measurements started after 20 minutes to ensure a steady state. Table 1 summarizes the used simulation and scenario setup.

Box plots show the median as solid line inside the box. The lower and upper quantile are shown by the boxes. Whiskers represent the interquartile range. The *latency* and the *recall*, i.e. how many of the targeted nodes have performed the transition, of the transition dissemination process allow to obtain open challenges in the execution process within the role assignment framework. The essential in-depth evaluation of the whole framework is planned for future work. In the following the results without self-healing are showed

Table 1: Scenario and simulation setup

Simulated Area	$1500\ m \times 1500\ m$
Max. Wi-Fi Range	$88\ m$
Cellular Latency	$200\ ms$, $\pm 100\ ms$
Max. Number of Gateways	$10 - 20\%$ of all nodes
Gateway Selection Interval	5 min
Movement Speed $[^{m}/_{s}]$	$1.5 - 2.5$
Density $[^{\text{nodes}}/_{km^2}]$	$22.2 - 88.9$
Transition Execution Location	Randomly selected client
Transition Dissemination Config.	All-to-All, GW + ad hoc local diss.



(a) Execution spread

(b) Recall

(c) Avg. latency

Figure 2: Evaluation results for the execution spread, latency, and recall of the transition dissemination.

to better understand the base system. The *execution spread* shows from the first occurrence of a transition how long it takes until other nodes in the network perform the same transition.

5.2 Insights into Transition Coordination

Figure 2 shows the results. The spread of a **single** transition from the centralized to the decentralized role assignment which was triggered on a local client coordinator is visible in Figure 2(a). The transition dissemination configuration (cf. Section 4.3) was used with *local upload* and *central dissemination* set to *gateway only* and *local dissemination* set to *probabilistic forwarding*. Thus, only gateway nodes used their cellular connection and received the transition information once it was uploaded from a gateway in the network. The initiating location is visible in the upper left part of the figure, where multiple adjacent clients received the transition information solely based on ad hoc communication between client coordinators of the role assignment framework. Other nodes, received the transition information from one of the adjacent gateways after it was uploaded by one of the former. This results in light green and darker green dots (i.e. execution within the sub second range) that show that after a gateway received the transition information the information is spread in the network using the local dissemination set to probabilistic forwarding in this exemplary case.

The recall and the average latency of the transition dissemination process are visualized in Figures 2(c) and 2(b) On the x-axis the maximum percentage of used gateway nodes for uploading or dissemination processes are shown. The y-axis shows both metrics over all ten runs for a multitude of transition decisions – every five minutes over the whole evaluation of 100 minutes. For comparison the transition dissemination is configured as follows: (i) *local upload* and *central dissemination* set to *all* without local dissemination and (ii) local upload and central dissemination to *gateways only* in combination with probabilistic local dissemination. It becomes apparent that if any system wants to benefit from transitions the coordination of the transitions (including the dissemination and any additional mechanisms such as self-healing) must be perform reliably so that transition decisions are received by every targeted instance in a decent amount of time in challenged networks. Figure 2(b) shows that even for the GW + ad hoc dissemination with only ten or 20% of the overall nodes used as gateways more than 90% of the nodes are reached in median relying on the small set of meaningful selected gateways further reducing the load on the cellular network. However, due to the nature of transitions the cost and performance trade-off concerning the coordination of transition in challenging networks becomes even more difficult.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we proposed the usage of transitions between role assignment schemes to enable offloading approaches to adapt to challenged networks. We propose and integrated centralized and decentralized role assignment schemes into the framework. Moreover, we detail the transition execution and coordination process in the framework. While offloading in its wide applicability for challenging networks is undisputed, offloading approaches still rely on single role assignment schemes which do become inefficient when network conditions or requirements change. The proposed role assignment framework enables adaptive offloading approaches for challenged networks. The role assignment framework is able to perform four main classes of transitions that enable wide applicability irrespective of the current network conditions: (i) from centralized to centralized assignment strategies, (ii) from centralized to decentralized assignment schemes, (iii) and vice-versa, and (iv) from decentralized to decentralized assignment strategies. In a first evaluation we highlight the transition coordination process in dynamic network conditions demonstrating open research challenges. The usage of different dissemination mechanisms to distribute transition decisions in the network shows that the cost and performance trade-off concerning the coordination of transition is an interesting research field especially in highly dynamic networks.

An in-depth evaluation of the proposed transition-enabled role assignment framework and its usage for mechanisms relying on offloading under changing network conditions is planned for future work. We are currently investigating how transitions within the role assignment framework affect the quality of the resulting assignment of gateways and clusters and consequently the performance of the offloading approach and any mechanism relying on the offloading.

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