Evaluation of Multi-operator dynamic 5G Network Slicing for Vehicular Emergency Scenarios

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***Abstract*—Dynamic network slicing involving multi-operator network resources is challenging due to lack of cooperation and inter-operability. Currently available slicing techniques focusing on static network configurations without run-time modifications and prioritization are insufficient to provide on-demand, instantaneous network slicing. With currently developed open-source platforms for virtualization and orchestration such as ONAP and ORAN, dynamic network slicing can be enabled. In this paper, a novel dynamic resource allocation scheme for dynamic 5G network slicing (DYSOLVE) is proposed and evaluated for a vehicular emergency scenario. DYSOLVE allocates both the radio as well as transport network resources of multiple network operators cooperatively and aims for slice cost optimization while ensuring service availability and QoS. Our performance evaluation shows significant improvements in the proposed DYSOLVE scheme compared to a traditional baseline approach with fixed resource allocation and without multi-operator cooperation.**

***Keywords*-Dynamic network slicing, 5G, Service Management and Orchestration Controller (SMO-C), ONAP, ORAN, SDN, Virtual Network, Multi Operator Core Networks**

I. Introduction

Future network technologies such as 5G are envisioned to provide tailored services to groups of users with defined Quality of Service (QoS). This is enabled by the concept of Network Function Virtualization (NFV) which allows to create specific end-to-end network slices. Network slicing splits a single physical network infrastructure into multiple logically isolated networks enabling elastic resource scaling and enhanced security and providing an illusion of end-to-end private networks [1]–[3].

In spite of several inherent advantages, current network slicing approaches pose the following challenges:

- no support of multi-vendor and multi-tenant networks as there is no common protocol available yet for creating an end-to-end slice covering a wide variety of hardware, software and network resources.
- no support of highly dynamic slice resource scaling; this frequently leads to situations where slice resources are under- or over-provisioned

This paper focuses on medical emergency scenarios and how dynamic network slicing could be beneficial in terms of cost and resource utilization. For an emergency scenario such as a natural calamity or an accident event, it is required that 5G network resources from multiple network operators can be dynamically allocated to an emergency responder network slice in order to effectively serve the strangled users and to provide relevant information to the affected people.

In case of a road or fire accident, the emergency response team is required to immediately reach to the place of the event to take people who are injured to a hospital. For that, the emergency response team's vehicle drives along a path recommended by some navigation tool. Appropriate radio and core network resources along this path should be reserved for the emergency response team so as to guarantee maximum connectivity as well as QoS. It is beneficial to have access to radio and transport network resources of multiple operators to provide highly available connectivity along the route to the hospital. Similarly, in case of natural calamities, the emergency service could establish a consensus between different network operators and take control of some network resources in the affected area for creating a private mobile network to support the rescue operation. For both use cases dynamic network slicing is the key concept. The slicing operation is controlled by the emergency responder network slice orchestrator.

In this paper, we propose a novel resource allocation scheme (DYSOLVE) for dynamic 5G network slicing tailored to the emergency scenarios described above. The performance of this scheme is evaluated through extensive simulations.

The paper is organized as follows. Section II outlines the motivation of network slicing as a key concept for providing a better quality of service and helping to speed up the service restoration process during a disaster event. Section III describes the basic concepts of dynamic 5G network slicing, and Section IV outlines the details of our slice resource allocation scheme. Section V presents our simulation model, and Section VI the performance evaluation results. Finally

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Section VII summarizes our findings and outlines our plans for future work.

II. Motivation

In emergency situations an excellent network coverage is of vital importance. Upgrading legacy emergency responder networks like FirstNet in USA or Tetra in Germany with new network technology, e.g. LTE would cost billions of dollars in investment. Utilizing a private emergency responder mobile network instance (slice) with dedicated fixed resources from a single mobile network operator on a contractual basis is expensive and might be prone to Quality of Service (QoS) degradation especially in case of congestion. Moreover, a slice with dedicated resources might be underutilized or overutilized for some time, respectively and thus does not provide a constant QoS [4], [5].

In case of an accident the average response time of an emergency response team is around 6.1 minutes (the median response time is 5.6 minutes and the range is from 9 seconds to 31.5 minutes) [8]. In a study of emergency medical services made in Turkey [9] it is stated, that the rate of emergency medical service calls varies depending on the day of the week, the time within a day, and the location. Therefore the dynamic demand-driven provisioning of resources (that might even belong to multiple network operators) for an emergency responder network slice is very beneficial in terms of QoS and cost.

Due to the absence of standard interfaces for configuration and management, current networks require vendor specific network element (NE) information and network management systems (NMS) for performing configuration changes. This increases the operational cost as it forces network operators to use multiple vendor specific NMS for performing orchestration or management tasks. To minimize the operational cost for dynamic network slice management and configuration an open source Service Management and Orchestration (SMO) System like the Open Networking Automation Platform (ONAP) [10] would be beneficial. Moreover, the Open RAN Alliance (ORAN) [11] proposes vendor independent RAN APIs. Thus, with ORAN and ONAP dynamic network slicing using the available network resources of multiple operators could be enabled. By that, an emergency responder team could request a network slice spanning over multiple operator domains on demand.

Therefore, in this paper we assume that the dynamic creation and adaptation of multi-vendor and multi-operator 5G network slices is feasible and outline an online resource allocation scheme for network slices to be used in medical emergency scenarios. The proposed scheme might be applied in other scenarios as well.

III. Dynamic 5G Network Slicing

This section outlines the basic concepts related to dynamic multi-operator 5G network slicing.

A. Network Virtualization and Slicing

The concept of network virtualization allows network operators to run multiple isolated network slices on a shared physical network infrastructure. The resources consumed by a network slice can be dynamically scaled (up/down) according to the traffic demand. The frequency of resource adaptation depends on the traffic and QoS requirement changes and the overhead incurred by the control plane traffic.

Definition. *Dynamic network slicing* is defined as real-time (in smaller time scales, i.e. seconds) allocation and deallocation of network resources to network slices depending on their priority and their service (traffic and quality) requirements.

B. Network Slicing Framework

Figure 1 shows a framework for creating end-to-end mobile network slices for emergency services using radio as well as transport network resources from multiple operators. In this scenario it is assumed that the emergency responder service provider operates an own mobile core network. Although, the network slice is a single entity, the slice creation and service instantiation occurs in multiple stages. In this paper we assume that the emergency responder service provider first negotiates with each operator an individual SLA wherein the cost for leasing transport and radio resources are specified. Later on, a single network slice is created and dynamically adapted by combining the leased resources[1]. In our specific use case the information about available resources is provided via ONAP [10] and ORAN [11] APIs to the network slice orchestrator and manager of the emergency responder service provider. The emergency responder network slice orchestrator passes this information to our DYSOLVE resource allocation algorithm for the selection of appropriate radio and transport resources. Finally, the end-to-end network slice is created using resources of multiple operators.

C. Network Slice Creation Process

Figure 2 shows the process flow to achieve dynamic network slicing. A key event is the arrival of a resource request. If the network slice does not exist yet, its initiation is triggered. Otherwise the slice has just to be updated, i.e. additional resources have to be provided. In case of a medical emergency scenario, a resource request would comprise the estimated vehicle (ambulance) path and the bandwidth and QoS requirement along this path. The path is defined from the start point (where the accident happened) of the ambulance till the destination (hospital). In another use case, the slice might be created and dynamically adapted (using resources from different network operators) to provide coverage within a geographical area and for highly

[1]The SLA negotiation and trust models are beyond the scope of this paper.

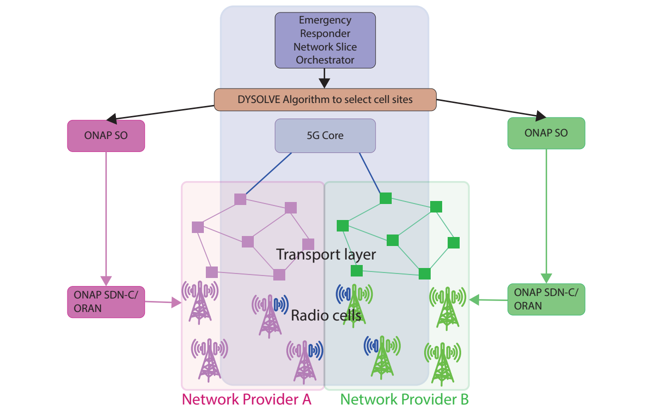

Figure 1. **Dynamic Network Slice Creation in a Multi-tenant network**

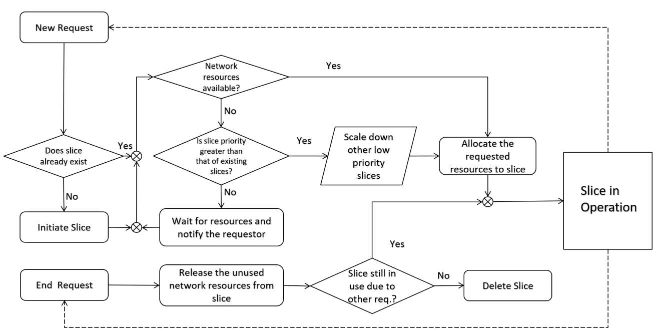

Figure 2. **Dynamic Network Slicing Process Flow**

fluctuating traffic demand. The next step is to check if the network resources are available. These includes the radio as well as the transport network resources. If the resources are unavailable, any low priority slices might be preempted to admit the request. The network slice is updated upon each request arrival and termination and it is deleted in case no ongoing requests are handled.

D. Example: Vehicular Emergency

In a vehicular emergency scenario ambulances moving towards a hospital require a highly available network slice allowing for high quality live video transmission along their path - typically a bandwidth of 10–25 Mbps is required [6]. This is achieved by the emergency responder network orchestrator collecting information about available transport network and radio resources from multiple operators and sending the resource configuration information to all the selected network entities to support the slice. In case of resource congestion, the prioritization mechanism evicts low-priority slices or scales down their resources when needed.

IV. DYSOLVE: Dynamic Slicing for Vehicular Emergency Scenarios

In the following, we describe our novel DYSOLVE approach for providing dynamic network slices tailored for vehicular emergency scenarios. The objective of DYSOLVE is to optimize the resource consumption of an emergency response service network slice while maximizing QoS and availability. The resource allocation optimization problem is constrained by the available radio and transport network resources and the minimum received signal strength index (RSSI) value.

A. Network Slice Cost

Table I lists the parameters used in the subsequent formulas.

Table I
Slice Parameters

Parameter	Explanation
C_{core}	Operational cost of private 5G core per day
C_{rt}	Cost of leased radio resources per hour per unit bandwidth (i.e. 25 Mbps)
C_{trans}	Cost of leased transport network resources connecting a radio cell to the 5G core per hour per unit bandwidth (i.e. 25 Mbps)
N_r	Average # of radio and transport network resource units required for handling one request (emergency call)
$Call_{day}$	Avg. # of requests (emergency calls) per day
T_{resp}	Avg. holding time (time of response) per request (emergency call) in hours
T_s	Total avg. usage (holding) time of all requests per day in hours
T_r	Total combined radio and transport resource usage per day in resource hours
C_T	Average operational cost of a slice per day

For a given day, the total usage (holding) time of all requests (in hours) is defined according to Equation 1, and the total combined radio and transport resource usage per day (in resource hours) is given by Equation 2. The operating cost of a network slice per day is the sum of the cost per day of the private 5G core (operated by the emergency responder service provider), and the cost of the transport network and radio resources leased from the network operators during a day. It is determined by Equation 3.

$$T_s = T_{resp} * Call_{day} \quad (1)$$

$$T_r = T_s * N_r \quad (2)$$

$$C_T = C_{core} + T_r * (C_{Trans} + C_{r_t}) \quad (3)$$

DYSOLVE provides the optimum selection of radio resources for a vehicular emergency response network slice according to Algorithm 1. Algorithm 1 requires as input the list of all possible radio cells which provide a minimum received signal power of -90 dB on each coordinate point on the path the ambulance travels from the accident site to the hospital. It then determines the radio cells that can serve the maximum number of points on the path with the required received signal power among all radio cells. This list of radio cells helps the ONAP Service Orchestrator to determine the

Algorithm 1: Cell Selection

```
Result: lr_slice, ho, nr
for i, p in enumerate (P): do
    lr_curr = get_cells(p)
    if len(lr_curr) == 0 : then
        nr.append(p)
        if i > 0 and len(lfr_prev) > 0 : then
            lr_slice.append(get_best_cells(lfr_prev))
        end
    end
    if len(lfr_curr) > 0 : then
        lfr_curr = intersection(lfr_curr, lr_curr)
        if len(lfr_curr)== 0 : then
            lr_slice.append(get_best_cells(lfr_prev))
            ho.append(P[i − 1])
            lfr_curr = intersection(lfr_prev, lr_curr)
        end
    else
        lfr_curr = lr_curr
    end
    lr_prev = lr_curr
    lfr_prev = lfr_curr
end
if len(lfr_prev > 0) : then
    lr_slice.append(get_best_cells(lfr_prev))
end
```

transport network resources required for connecting all the selected radio cells to the mobile core network (which is operated by the emergency response service operator). The parameters used in Algorithm 1 are listed in Table II.

V. Simulation Setup

In this section we describe the simulation setup which we use to evaluate our dynamic network slicing concept.

A. Event of Accident Scenario

The following scenario is simulated: for an accident recovery, the emergency response team (ERT) navigates towards the destination (e.g., a hospital) on a shortest path using a map tool. Based upon the emergency level of the accident, the ERT also knows the priority of the event. This information is used to request for network resources required for a given time and within an area to perform an essential call, e.g. a live video connection. Knowing the requests (i.e. the navigation routes and the bandwidth and QoS requirements) of all ambulances currently serving high priority events, the emergency responder service orchestrator continuously adapts the emergency responder network slice by leasing the appropriate radio and transport network resources from the operators. Upon reaching the destination (hospital), the network slice resources used by an ambulance are released. If no emergency event is active the slice is deleted through the orchestrator.

Table II
Algorithm 1 Parameters

Parameter	Explanation
P	List of points on the navigation path
p	Coordinates of a point
$get\_cells(p)$	Method to retrieve the radio cells which provide minimum received signal power of -90 dB around a given coordinate point p
lr_{slice}	List of selected radio cells for a given path
lfr_{curr}	Filtered radio cells around a given point on the path
lfr_{prev}	Filtered radio cells from a previous point on the path
lr_{curr}	List of radio cells around a given point on the path
lr_{prev}	List of radio cells from a previous point on the path
nr	List of points on the path P which do not yield a minimum received signal power of -90 dB from a radio cell
ho	List of points best suitable to perform handovers on the path
get_best_cells	Method to select the best radio cell from the list of available radio cells based on the ”Average Received Signal Power” in dB
$intersection(a, b)$	Method to get a common list of radio cells from two different lists of radio cells a and b as inputs

B. Setup Details

The scenario explained above is realized by simulating random vehicular (ambulance) paths within an area where a given cellular coverage is provided by two different network operators. The size of the area is adapted from a typical county in the state of New Jersey (NJ), USA. Each path is triggered by an emergency event and lead to a resource request to the emergency responder network slice. The resource requirement for a given ambulance driving along the path to the hospital is assumed to be fixed (25 Mbps). The average number of emergency calls within a day and the average time of response (holding time) were derived from the The Office of Emergency Medical Services (OEMS) [13] statistics.

In the following our assumptions are summarized:

- each cell operates in the 2.6 GHz range.
- both operators have a pre-defined SLA with the emergency responder network provider to agree on resource leasing.
- 20 random paths ranging from 5 km to 15 km are generated.
- the transmit power of all radio cells is fixed to 45dB.
- a radio cell is only selected if the received signal strength index is greater than or equal to -90 dB.
- a received signal strength index of less than -90dB is considered as a blind spot (coverage gap).
- the Alpha Beta Gamma Non-Line of sight path loss model is used, where the α, β, γ and σ values are

taken from [7] for a frequency range between 2 GHz and 18 GHz
- a step size of 250m is considered for the waypoints of the vehicular path.
- average number of emergency calls within a day: 31
- average time of response (holding time): 17 minutes

C. Simulation Cases

We perform the simulation for both a baseline as well as for the DYSOLVE case. For both cases, a radio cell is only selected if it provides a minimum guaranteed radio signal strength (-90 dB). The core network resources of the emergency responder network slice are assumed to be fixed and allocated permanently (as it is a private 5G core operated by the emergency responder service provider).

Baseline. In the baseline case, radio and transport network resources of only one network operator are used by the emergency responder network slice and are allocated permanently.

DYSOLVE. In the DYSOLVE case, radio and transport network resources of both operators might be used by the emergency responder network slice. Dynamic resource allocation and resource leasing from both operators is enabled. The resource allocation is performed by the DYSOLVE algorithm 1 as stated above.

VI. Performance Evaluation

A. Performance Evaluation Metrics

The following performance metrics are used in the baseline and the DYSOLVE case:

- network slice availability along a path.
- cost of operating a slice (per day).
- radio resource usage of a slice.

The network slice availability is defined as the coverage fraction along a path for a given slice. The network availability percentage value is given by $(d_{covered}/d_{total}) * 100$ wherein $d_{covered}$ and d_{total} are the path length with coverage and the total path length, respectively.

B. Network Slice Availability Evaluation

In the simulation 20 random paths are generated within an area which is served by 156 radio cells of each network operator. For the baseline case in total (i.e. for all 20 paths) 60 blind spots were observed corresponding to an availability of 92.57%.

For the DYSOLVE case taking the same 20 paths only three blind spots were identified corresponding to an availability of 99.62%.

C. Slice Operational Cost Evaluation

As the core network resources used by a slice are the same in the baseline and the DYSOLVE case, the cost comparison is only carried out considering the radio and transport network resources.

In the baseline case for supporting the 20 paths at least one unit bandwidth (25 Mbps) of all 156 radio cells (of one operator) and for the respective transport connections to the private 5G core are required. (remark: this is the best case, assuming that not more than one ambulance will be connected to a cell at the same time). Furthermore, without dynamic resource allocation, all leased resources are permanently allocated i.e. the emergency responder network slice is active 24 hours per day. Therefore, the lower bound of the cost of this slice per day can be calculated as follows: For the usage time $T_s = 24 hours/day$, and the average number of used radio and transport network resource units $N_r = 156$, the resource usage in resource hours per day is given by Equation 4:

$$T_r = T_s * N_r = 24 * 156 = 3744 \tag{4}$$

Using Equation 4, the total operational cost of the slice per day in the baseline case is determined by Equation 5:

$$C_T = C_{core} + 3744 * (C_{Trans} + C_{r_t}) \tag{5}$$

In the DYSOLVE case, with $Call_{day} = 31$, and $T_{resp} = 17/60$ hours, the total usage time (holding time) in hours of all requests within a day is calculated via Equation 6:

$$T_s = Call_{day} * T_{Resp} = 31 * 17/60 \approx 9 \tag{6}$$

In the DYSOLVE case 119 radio cells are selected to cover all 20 paths. Thus, the average number of used radio and transport network resource units required for handling one request (i.e. path) is $N_r = 5,95$. The total resource usage in resource hours per day is determined by Equation 7:

$$T_r = T_s * N_r = 9 * 5,95 = 53.55 \tag{7}$$

Finally, the total operational cost of the slice per day is derived from Equation 8:

$$C_T = C_{core} + 53.55 * (C_{Trans} + C_{r_t}) \tag{8}$$

It can be seen that by applying DYSOLVE the daily cost for leasing radio and transport network resources for a emergency responder network slice can be reduced to about 1.5% compared to the baseline case.

D. Evaluation Summary

A comparison of the performance evaluation results for the baseline and the DYSOLVE case is shown in Table III. It can be seen that by applying DYSOLVE 98.5% (radio and transport network leasing) cost savings can be obtained compared to the baseline case while providing a higher network slice availability.

Table III
EVALUATION SUMMARY

Eval. Parameter	Baseline Slice	DYSOLVE Slice
Number of paths	20	20
Provider A number of cells	156	156
Provider B number of cells	156	156
Sum of path lengths	202 km	202 km
Mean path length	10.10 km	10.10 km
# of path measurement points	808	808
Selected # of cells for 20 paths	156	119
Mean number of radio cells used per request	156	5.95
Cost of radio & transport network resources per day (C_d)	$3744 * (C_{trans} + C_{rt})$	$53.55 * (C_{trans} + C_{rt})$
# of blind spots	60	3
Sum of path sections with no coverage	22.25 km	1.5 km
Network slice availability	92.57%	99.62%
$C_d/C_d^{baseline}$	1	0.02
Mean share of path sections without coverage	11.0%	0.7%
Mean number of blind spots per km	0.297/km	0.015/km

VII. CONCLUSION

This paper proposes a novel approach for dynamic network slicing and demonstrates the applicability by means of a vehicular emergency scenario. The DYSOLVE resource allocation scheme determines the required radio and transport network resources on demand per request and updates the emergency responder network slice accordingly to achieve continuous network connectivity for emergency vehicles along their navigation paths from accident sites to the hospital. The resource selection decision of DYSOLVE serves as input to an ONAP based service orchestrator. Our performance evaluation results show, that by applying the DYSOLVE scheme high availability, cost effectiveness, and optimum resource utilization is obtained – e.g., a cost reduction (in terms of radio and transport network resource leasing cost) larger than 95% can be achieved compared to the baseline case (with fixed resource allocation). In our future work we intend to implement DYSOLVE on a real life edge cloud testbed such as COSMOS [14] and consider an autonomous driving use case with varying load and network conditions.

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