An integrated-multi-RAT framework for multipath-computing in heterogeneous-wireless network

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**ABSTRACT**

The bandwidth-intensive applications on Smart-Mobile-Devices (SMDs) are increasing with SMD's colossal growth. The overlapped cellular and non-cellular networks, in hot-spot-places, and SMDs capabilities are significant reasons for this growth. SMD's interfaces-RAT (Radio-Access-Technology) can have complementary link characteristics. The end-users can avail always-best-connectivity (ABC) on their SMDs with complementary RAT characteristics. This paper proposes an Integrated-multi-RAT-utilization (Im-Ru) framework for multipath-computing support to realize ABC for the end-users. The Im-Ru framework has two approaches. The First is a hybrid-RAT-discovery model based on SMD's interfaces, current-location, and identification using ANDSF and MIIS servers. The second is the user’s preference-based RAT-selection using weighted-RAT-parameters. We observe that the Im-Ru framework for multipath-computing is useful in future 5G-NR networks. We analyzed the Im-Ru’s performance related to average-throughput improvement over the existing approaches for SMD's different speeds and observed a significant improvement. The experimental results show that Im-Ru is more reliable by realizing lower packet-loss and delay than existing work.

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1. Introduction

The heterogeneity of mobile and wireless Internet is increasing with the improved capabilities of SMDs (Mueller et al., 2009). There are two main reasons for this growth. First, the development of hot-spot places at any location for mass business/social gatherings (Ekici & Vuran, 2010). Second, the SMDs have multiple interfaces, giga-bytes of memory & terabytes of storage capacity, high processing, and other resources. Each SMD's interface is connected to a wireless network with its radio access technology (RAT). Every RAT has different link-level characteristics, such as bandwidth, coverage, operating costs, reliability, and speed (Mueller et al., 2009). These RATs have complementary properties and can be used opportunistically if the supporting technologies are developed. The overlapping RATs can be utilized concurrently, while the non-overlapping RATs can provide
the service continuity opportunistically. For such an arrangement of RATs, we call integrated multi-RAT utilization (Im-Ru). The end-users can select the networks according to their preferences using Im-RU. The SMD achieves Always-Best-Connected (ABC) scenario (Gustafsson & Jonsson, 2003) for the end-users with Im-Ru assistance.

SMD switches the in-service RAT to a candidate RAT (can be different) to implement these flexibilities for an end-user. The switching of RATs is called handover. The handover is possible between the same RATs (horizontal handover) or different RATs (vertical handover or VHO). VHO is completed using handover initiation (RAT Discovery), handover negotiation (Handover time estimation), and handover execution (New RAT/channel selection/allocation to SMD). These steps are significant in the Im-Ru for efficient multipath computing. Besides VHO, there are many other challenges to implement Im-Ru, such as capturing accurate RAT information, processing it, and selecting the most preferred RAT according to their requirements. These all are the architectural and computing issues of Im-Ru. The top leading wireless domain companies like CenturyLink Inc., CISCO Systems, Qualcomm Inc., LG Inc., interdigital Inc., Fastback Networks, NOKIA corp., and others¹ are putting their efforts to develop the Im-Ru-enabled products and services to utilize SMD’s interfaces concurrently.

This paper focuses on proposing an Im-Ru framework for multipath computing that can be applicable in 5G-NR networks (Dahlman et al., 2020). The Im-Ru framework consists of a hybrid RAT discovery model based on the supporting interfaces, current-location, and identification of SMD with the assistance of MIIS (Medium-Independent Information Service) of IEEE 802.21 framework (IEEE 802.21 Working Group & others, 2009). The discovered RAT’s Radio Access Network Information (RANI) is captured from MIIS’ information elements (IEs). We analyze the RATs with their parameters and apply a weighted-parameters based method to find an optimal rank of RATs. According to the end-users specified parameters weight, the system recommends the highest rank RAT for the SMD. We model the RAT selection procedure mathematically using Grey Relational Analysis (GRA) using received signal strength (RSS) of RAT to verify our proposed approach (Deng, 1989). We observed the user’s QoE and compared them with similar work in this area. We studied a handover time, particularly in VHO, by reducing network scanning and forwarding authentication from the current RAT to the candidate RAT. We simulate the proposed approaches in ns-2.29 (NS, n.d.) using NIST mobility package (NIST, n.d.). The results demonstrate the utility of our approaches. The significant contributions of the proposed approaches are given below:

- A hybrid model of RAT discovery using MIIS’ information elements (IEs).
- A weighted-parameters based RAT selection using the proposed optimal-rank computation Algorithm.
- Mathematical modelling of optimal RAT selection in terms of RSS using Grey system theory (Deng, 1989).

1.1. Background and preliminaries

SMD’s mobility means that it undergoes a handover by switching its current point-of-attachment (PoA) with a new PoA in a visited network. Handover is either soft, a
make-before-break approach, or hard, a break-before-make approach (Ghahfarokhi & Movahhedinia, 2013; IEEE 802.21 Working Group & others, 2009; la Oliva et al., 2011).

### 1.1.1. Handover in heterogeneous networks

A heterogeneous network is a group of colocated networks with different link-layer technologies (Nguyen & Bonnet, 2006). In a heterogeneous wireless network, SMD’s mobility management process keeps its connectivity intact when it moves over the cells with the same or distinct RATs by changing the PoA through VHO (Rajavelsamy et al., 2007). The SMD moves at different speeds over a different or same autonomous system (AS) (Fernandes & Karmouch, 2012). The SMD’s such mobility behaviour is known as macro and micro-mobility, respectively. The VHO and location finding services are part of SMD’s mobility management process in heterogeneous wireless networks (Andersson, 2012). We use this process in our proposed model to find SMD’s location and achieve its micro and macro mobility. SMD’s mobility management process is implemented across the protocol stack (Andersson, 2012).

The typical VHO’s link-layer issues are SMD’s leaving from the current APs/eNodeBs/BSs and joining the next APs/eNodeBs/BSs, SMD’s authentication at next APs/eNodeBs, and transmission of leftover/lost data-frames to the SMD, post-VHO (T.-s. Kim et al., 2009; Yokota et al., 2002). Additionally, we need a mapping process between multi-RAT frames to deliver them across the different SMD’s interfaces (Malathy & Muthuswamy, 2018).

Fundamentally, mobile-IP (MIP) provisions the mobility issues at network layer (Perkins, 2002). Mobility solutions are either SMD-controlled or network-controlled. The SMD-controlled mobility management process considers two addresses to handle the mobility; one is SMD’s home routers’ IP address, and the other is SMD’s temporary IP address assigned by the SMD’s foreign/visited networks’ router. The SMD’s IP address maintained by foreign/visited networks is known as care-of-address (CoA). The SMD can also get a CoA assigned through the DHCP query; such CoA is known as colocated CoA (Perkins, 1997). Whenever SMD moves to a foreign network, it has to inform about its new CoA to its home network using signalling for a location update so that the home network would forward the arrived packets to SMD’s new CoA in the future using IP-in-IP encapsulation (I-PIPE) (Perkins, 2002). Here, the question is, what are the SMD’s requirements to move seamlessly? We identified the following requirements (Malathy & Muthuswamy, 2018):

- A quick RAT scan to find the APs/eNodeBs/BS prefixes.
- Capturing RAT’s information and list the prefixes of APs/eNodeBs/BSs.
- Optimal RAT selection after processing the RAT’s information.

### 1.1.2. MIH services

Media Independent Handover or the MIH services provides a framework that supports SMD’s seamless mobility over the multi-RAT heterogeneous networks (IEEE 802.21 Working Group & others, 2009). We use MlIS of MIH services in the implementation of the Im-Ru framework. The MIH service standard facilitates the change of PoA with variable SMD’s speed, bandwidth, and data transfer between SMD and network infrastructure.
The network infrastructure consists of SMD’s location, higher layer services, and network-cells in SMD proximity (Malathy & Muthuswamy, 2018). The link-measurement reports contain information on network infrastructure, RSS, frame error rates, and SMD’s time synchronization with MIIS servers (IEEE 802.21 Working Group & others, 2009). The link-layer triggers a handover based on these reports (Machań & Woźniak, 2010; Singh & Singh, 2013).

The MIH standard offers three MIH services to support VHO; Media Independent Information Service (MIIS), Media Independent Event Service (MIES), and Media Independent Command Service (MICS). MIES starts the detection of variable logical link characteristics using MIH and link events. The link-events bring a physical link’s information of the local physical layer and give it to local MIH-function. The MIH-events bring a physical link’s information from local and remote physical layers. A remote-MIH event propagates a group of links from a remote MIH-function to the local MIH-function. A measurement report stores the link information to assist in the handover process (IEEE 802.21 Working Group & others, 2009; Malathy & Muthuswamy, 2018). MICS finds the link’s status through MIH-user commands and controls the SMD for its optimized performance. MICS offers separate commands for local and remote MIHF (IEEE 802.21 Working Group & others, 2009). MIIS captures radio access network information (RANI) in the IEs about RATs in SMD’s proximity (IEEE 802.21 Working Group & others, 2009). We have used MIIS and its IEs for the proposed integrated multi-RAT utilization approaches.

These services process the measurement and link-layer triggering reports (IEEE 802.21 Working Group & others, 2009). MIH Function (MIHF) initiates the MIH events. MIHF uses link-layer triggers for initiating and preparing a VHO. There are three steps in a handover initiation; discovering RATs, selecting a RAT, and negotiating RAT’s QoS (IEEE 802.21 Working Group & others, 2009; Malathy & Muthuswamy, 2018). A handover preparation has two phases; resource reservation and connectivity with lower and upper layers (IEEE 802.21 Working Group & others, 2009). A handover execution helps end-users choose a suitable RAT for their SMDs from the multi-RATs for its ongoing or new data connection using MIHF (IEEE 802.21 Working Group & others, 2009).

1.1.3. VHO performance issues
The multi-RATs help extend the coverage area of heterogeneous wireless networks. In such a multi-RAT extended network, VHO realizes the user’s flexibility, multi-RAT’s cost-effective utilization, and achieves load balancing (Heidarpour & Manshaei, 2020). An efficient design of VHO realizes SMD’s seamless mobility and multi-RAT utilization (Golmie, 2009). The VHO performance depends upon the overall time incurred in its execution (IEEE 802.21 Working Group & others, 2009; Li et al., 2018). The VHO execution time is the sum of times taken in RAT discovery, RAT’s received signal strength (RSS) measurement, optimal RAT selection according to the user preferences, and passing the authorization of user credentials from present RAT to next RAT (Kassar et al., 2008).

In VHO, important decision factors are involved, like VHO decision criteria, policies, algorithms, and control schemes (Kassar et al., 2008). Kassar et al. (2008) described some decision criteria of VHO, such as user preferences, network conditions (RSS, QoS parameters, mobility pattern), application requirements (SMD’s speed), and SMD’s capabilities such as its memory, battery, interface support.
The rest of the paper is further organized in different sections. Section 2 provides a brief related work. Section 3 presents the proposed approaches to realize the IM-Ru framework for multipath computing applicable for SMD in heterogeneous networks. These proposed approaches are hybrid RAT discovery and weighted parameter based RAT selection. Section 4 presents an experimental setup, performance evaluation, and result analysis. The Section 5 concludes the paper.

2. Related literature review

The network entities support multiple link-layer technologies for communication. While the SMD is moving, the available coverage of RATs has to be detected and selected for the smooth handover and Im-Ru. The bandwidth demand increased for SMD applications in the recent past. The researchers proposed a few solutions to meet such demands as multihoming, multistreaming, and multipathing. These solutions are either sender or receiver centric, but the objective of all is the ubiquitous and instant connectivity on the mobile Internet. One such receiver centric solution is proposed by Cao et al. (2019). To find the research gap in this area, we surveyed the reputed literature to identify the proposed work and is presented in this section. The IM-Ru is the least explored area. Most of the existing work of IM-Ru is based on IEEE 802.21-MIH standard framework (IEEE 802.21 Working Group & others, 2009). Ghahfarokhi and Movahhedinia (2013), and Khattab and Alani (2013) described the VHO approaches proposed and categorized them based on the mobility management protocol used. The authors compared their performances and concluded that MIPv4 under MIH is better than MIPv6 for mobility scenarios. Different applications of MIH in next-generation wireless networks are described as in Ghahfarokhi and Movahhedinia (2013). Kao et al. (2012) proposed that the incurred cost in the integration of multi-RATs using MIH is higher and proposed a low-cost implementation of IEEE 802.21. Bożek and Pacyna (2010) describe the use of MIH mechanism for the handovers between WLAN and ethernet link and shows some ambiguities in the current MIH implementation. Different handover algorithms based on signal strength, interface type, cost, and different thresholds have already been defined. Hebbi and Saboji (2009) proposed a VHO algorithm based on the SMD’s movement speed among heterogeneous wireless networks. Kumar and Tyagi (2010), implemented the media-independent handover between WLAN and UMTS using IEEE 802.21 events. Yoo et al. (2008) proposed a handover prediction method by estimating the required time of the VHO in heterogeneous networks. This proposal produces link triggers to finish the VHO before the running link goes down using the neighbouring network information.

One of the most challenging aspects of the mobile Internet is RAT discovery, and its variable link characteristics as the SMD moves. Yaqub and Zhang (2006) proposed an autonomous network discovery method for heterogeneous networks. Yaqub and Zhang (2006) generated a preferred network list and saved it as ‘known networks’ in SMD’s memory with each network’s location information, even after SMD departed from these networks. The SMD selects one of RAT from the ‘known networks’ list to reduce the VHO time because the list is saved in its local memory (Yaqub & Zhang, 2006). The SMD saves all movement history from the start, all visited networks, and their cell information. The most preferred RAT has been selected based-on its RSS and timestamps(TS) values (Yaqub & Zhang, 2006). The SMD does not get any assistance
from the network, information servers, or other mobile devices for RAT discovery (Yaqub & Zhang, 2006). Mueller et al. (2009) describe a procedure for managing the multi-RATs to discover the non-cellular neighbouring networks using a generic advertisement service in a make-before-break manner. The authors used the 3GPP standard method of RAT discovery and selection to find the information cellular neighbouring networks (Mueller et al., 2009). Andrei et al. (2010) proposed an improved MIIS server architecture to discover RATs. SMD queries this MIIS server by sending its location coordinates and radius of the coverage area. The improved MIIS servers are placed at APs/BSs to manage all MIIS servers and maintain a database of multi-RATs globally (Andrei et al., 2010).

Eva Gustafsson gave the almost first proposal on the usage of combined RATs, and others (Gustafsson & Jonsson, 2003) in their work titled ‘Always Best Connected (ABC).’ We got motivated to do this work after going through the ABC concept (Gustafsson & Jonsson, 2003). The authors described the relationship between business and user experiences. Although this work provided enough motivation to integrate multi-RATs, yet the work lacked in technical implementations. Koutsorodi et al. (2006) proposed an SMD-initiated and controlled RAT selection in heterogeneous mobile networks using the intelligent access selection (IAS) method. The IAS detects an optimal local interface and its PoA based on weights of parameters, such as RAT status, resource availability, user preferences, and service requirements. Kassar et al. (2008) investigated a handover management process to realize the ABC concept. This work proposes context-awareness in the initiation, planning, and execution of VHO. Park and Chung (2009) used location boundary detection function (LBDF) to discover neighbouring network information by indexing each network with an index number. The authors proposed the RAT selection method based on user preferences and index numbers without using RSS, RTT, and packet loss rate of networks (Park & Chung, 2009). The authors used GPS servers to detect the SMD’s location and related network service area to implement VHO, as shown in Figure 1, Park and Chung (2009). T. Kim et al. (2010) proposed a QoS-aware VHO algorithm by evaluating the service’s history of each candidate network to minimize the frequent network switching and disconnection based on its bandwidth, cost, data rate, delay, SMD’s cumulative service time since the previous handover, and SMD’s time since the last handover blocking. Corici et al. (2011) proposed a RAT discovery and selection of cellular multi-RAT using the network component ‘access network discovery and selection function(ANDSF),’ and the SMD component ‘mobility manager function(MMF) of evolved-packet-core(EPC) in heterogeneous wireless networks. Payaswini and Manjaiah (2013) used cross-layer information to make handover decisions to help SMD achieve always best connected(ABC) Gustafsson and Jonsson (2003). RAT selection based on heterogeneous network load awareness was reported in Gerasimenko et al. (2013). The considered heterogeneous network was having two RATs, WLAN and LTE. The authors compared the proposed scheme with RAT selection methods based on RSS in WLANs. Andreev et al. (2014) further investigated IAS by reviewing the major challenges of user experiences in the converged WLAN and LTE networks with smaller cells and provided uniform network connectivity for Im-Ru. Andreev et al. (2014) envisioned that Im-Ru would be a part of 5G networks, and the ISM band of WLAN will centrally control the LTE networks to optimize the user’s and operator’s perspectives. The authors proposed a novel space-time based RAT selection technique based on captured dynamic random traffic of multiple RATs. Abdullah et al. (2014) proposed an EARD (enhanced access
router discovery) algorithm. An EARD was proposed for WLAN and Wi-Max. The EARD used the parameters like bandwidth(B), cost(C), number of lost packets(L), and network delay(D) & jitter(J) of a packet transmitted. The EARD used PRMC (priority ratio for multiple criteria) as given in Equation (1).

\[
N = \{B, L, J, C, D\}
\]  

Where \(N\) denotes the number of parameters used in PRMC. Four traffic classes were used by authors, namely voice, video, background, and best effort. The priority ratio of each parametric criterion is calculated after assigning the priority to each criterion. The priority ratios are calculated using the Equation (2) to define the user preferences clearly, where \(n\) is the parametric criteria used.

\[
PR_i = \frac{N_i}{\sum_{i=1}^{n} P_i}
\]  

Lahby et al. (2015) compared the performance of various MADM (multi-attribute decision making) methods in the literature like SAW, TOPSIS & E-TOPSIS, DIA, MEW, FADM, and VIKOR (Zavadskas et al., 2014) to implement the seamless RAT selection. The objective of this comparison was to achieve seamless RAT selection to ensure the principle of ABC. El Helou et al. (2016) proposed a hybrid model of RAT selection by broadcasting the cost and QoS information in heterogeneous wireless networks to help users select a preferred RAT. The authors try to get a win-win situation for both users and network

![Figure 1. VHO steps proposed by Park and Chung (2009).](image)
operators by proposing two independent decision-making techniques to achieve the operator’s objectives and others to ensure the user’s utility (El Helou et al., 2016). Wu and Du (2016) developed a RAT selection technique by defining a utility function, which considers the QoS requirements and preferences of end-user with channel state, cost, and network load. Li et al. (2018) proposed a system’s view of multi-RAT utilization. Heidarpour and Manshaei (2020) proposed a general framework to share bandwidth among multi-RATS, used ANDSF (3GPP, 2014) to integrate 3GPP and non-3GPP RATS.

2.1. Identified research gap

Most of the proposals on ‘access network discovery and selection’ focussed on a few criteria for VHO in wi-fi and 2G/3G, as shown in Table 1. In contemporary work, the utilization of IEs using MIIS to discover and choose the RATs is least discussed. Radio access network information (RANI) is critically significant to discover and choose the RATs. However, the literature has used RANI in a limited manner. Finding RANI in a distributed and recursive manner on the Internet will enhance the performance of integrated Im-Ru for multipath computing, which may be applicable in 5G New Radio (NR) networks (Dahlman et al., 2020). We proposed an Im-Ru framework to bridge the above research gap for multipath computing in 5G heterogeneous networks. In this work, we model ‘Hybrid RAT Discovery and weighted-parameters based RAT Selection,’ with the following contributions:

- Capturing of RANI contained in IEs by proposing a hybrid model of RAT discovery using MIIS of IEEE 802.21 (IEEE 802.21 Working Group & others, 2009)

| Table 1. Review summary of mobility, VHO, RAT discovery & selection. |
|-------------------------|-----------------|------------------|------------------|
| Objectives               | Approach                           | Implementation metrics | Research                                      |
| Vertical handover (VHO)  | Standard framework to support VHO, reducing VHO frequency & time by evaluating each RAT for BW, delay and cost and by estimating the cumulative service time since last VHO and duration since last VHO blocking | RSS, interface types, BW, delay, cost, security, energy, link condition, & performance | IEEE 802.21 Working Group and others (2009), Ghahtar and Movahhedinia (2013), Khattab and Alani (2013), T. Kim et al. (2010), Nasser et al. (2006), Chou et al. (2006) |
| Mobility management      | Mobile-IP based, cross layer method to support mobility in het-nets, behaviour-based mobility prediction using daily movement patterns of SMD blocking | RSS, Coverage, SINR, cross-layer metrics and movement history | Perkins (2002), Banerjee et al. (2003), Das et al. (2002), Ramjee et al. (2000), Campbell et al. (2000), Snoeren and Balakrishnan (2000), Wanalertlak et al. (2011) |
| RAT discovery            | Autonomous discovery LBDF, RAT indexing, generic advertisement service and ANDSF, MIIS-based approach, ANDSF using EPC | Location of BS/AP, movement history of SMD, RSS, time-stamp, co-ordinates & radius of coverage area, BW, cost, packet loss delay & jitter | Yaqub and Zhang (2006), Park and Chung (2009), Mueller et al. (2009), Andrei et al. (2010), Corici et al. (2011), Abdullah et al. (2014) |
| RAT selection            | RAT selection based on past performance, weighted parameters using MADM | Preference RAT list, BW, network load, cost, QoS, network channel state | Lahby et al. (2015), Zavadskas et al. (2014), Andreeev et al. (2014), Koutsoriodi et al. (2006), Gerasimenko et al. (2013), El Helou et al. (2016) |
| Always best connected (ABC) | Ensuring ABC with both user’s and operator’s perspectives | RSS, type of interface app layer information, context-aware handover info. | Gustafsson and Jonsson (2003), Kassar et al. (2008) |
A wireless mobile network scenario having a single UMTS, 3 Wi-Max, and 17 WLAN cells, is proposed as the network topology for the simulation using ns2.29 (NS, n.d.) with NIST mobility package with MIH capabilities (NIST, n.d.) and NIST add-ons (NIST IEEE 802.21 Addon, 2007).

Discovery and access selection process (DASP) approach based on the classic ANDSF standard (3GPP, 2014).

An algorithm for RAT selection using optimal ranks of RATs based on weights multiple parameters.

A mathematical model of RSS based RAT selection using Grey System Theory (Deng, 1989).

We frame here the related research questions (RRQs) to answer RAT discovery and selection problems. These RRQs are as follows:

• **RRQ1**: Realization of Hybrid RAT Discovery Process under Mobility Constraints - For multi-interface enabled SMDs, how mobility constraints, specifically VHO and SMD’s moving speed, affects the RAT discovery model? How a hybrid RAT discovery model provides reliable RATs timely before the serving RAT goes down?

• **RRQ2**: Weighted-parameters based RAT Selection - How weighted-parameters values of SMD RATs will provide the preferred RAT selection for end-users in heterogeneous wireless mobile networks?

A solution to these RRQs will be studied in the next section.

### 3. Integrated multi-RAT utilization framework

This section discusses the proposed approaches for the Im-Ru framework for multipath computing that can also be applicable in 5G heterogeneous networks. The proposed approaches are hybrid RAT discovery and weighted parameters-based RAT selection. First, we present a considered multi-RAT environment, which also forms our simulation topology. Next, we explained the proposed methods of storing the multi-RAT information with RANI and IEs of MIIS. RANI is the generic information of SMD and RATs, while IEs contain RANI and specific information of candidate RATs. Next, we present a hybrid model of RAT discovery, followed by the discovery and access selection process (DASP). Next, we present an abstract model of SMD to implement DASP and other functions. Next, we describe a multi-criteria selection function to get the optimal rank of candidate RATs. Next, we present an algorithm for proposed RAT discovery and selection. The section concludes with an RSS-based analysis model of optimal RAT selection using Grey system theory (Deng, 1989) to verify and validate the proposed selection method of RATs theoretically.

#### 3.1. Radio access network information

The SMD captures required radio access network information (RANI) for handover from MIIS servers (IEEE 802.21 Working Group & others, 2009), as proposed in Figure 2. RANI of RATs is captured from local or remote MIH-function, depending upon the availability of RATs. RANI is fetched proactively through serving-PoA(UMTS) or executing a query.
into the MIIS server database periodically. RANI contains the information related to a wireless network and mobile nodes, as shown in Table 2. The RANI parameters are passed into the proposed Algorithms 1 and 2 to obtain an optimal rank of RATs.

### Information Elements

Information Elements (IEs) store the generic and specific information about the candidate RATs.

#### Table 2. RANI for SMD and wireless heterogeneous network.

| Information                                      | Description                                      |
|--------------------------------------------------|--------------------------------------------------|
| List of APs/BSs                                  | to decide candidate PoA                          |
| Capacities of APs/BSs                            | for handover                                     |
| Service support from upper layers                | to RATs through cross-layer                      |
| List of authorized users                         | for pass authorization to candidate PoA           |
| QoS for ongoing sessions                        | through parameter negotiation                    |
| Users per PoA                                   | to avoid losses                                  |
| Uplink and Downlink load                        | for load balancing                               |
| Free bandwidth                                  | for admission control                            |
| Discovered Networks                             | to update list of new RATs                       |
| Attributes context switching                     | for context awareness                            |
| Physical-layer parameters                       | for spectrum-aware switching                     |
| Measured QoS experienced for RAT                 | to match with required QoS                       |
MIIS server creates a global-view of multi-RATs using IEs. The IEs contain features of every RAT in a particular coverage area. The IEs contain data related to a particular operator’s inter-RAT mobility methods and link configuration information for intra-RAT local mobility methods (IEEE 802.21 Working Group & others, 2009), as shown in Table 3 (IEEE 802.21 Working Group & others, 2009). Generic or specific information stored in IEs are passed into the proposed Algorithms 1 and 2 along with RANI, to obtain an optimal rank of RATs using multi-criteria function given in Equations (3) and (4).

3.3. Hybrid model of RAT discovery

We present here our proposed hybrid RAT discovery model with the help of RANI and IEs as shown in the Figure 2. The RAT discovery is distributed in the group of MiIS and ANDSF servers, and client-server based in between SMD and nearest MiIS and ANDSF server (Tseng et al., 2013). We use a randomized discovery to implement distributed method within the group of MiIS and ANDSF servers, and a deterministic discovery method in between SMD and nearest MiIS servers (Tseng et al., 2013). We assume that SMD’s UMTS interface is always in ‘on’ state, because UMTS consumes less battery power compared to wi-fi and Wi-Max, and has wide coverage. Whenever SMD is connected to wi-fi or Wi-Max, RAT discovery continued on UMTS to find RAT’s RANI, and IEs. The Algorithms 1 and 2 takes RANI and IE’s as arguments and returns an optimal rank of RATs using multi-criteria function given in Equations (3) and (4). Further, packages of different RATs are formed by the proposed Algorithms 1 and 2 if multiple wireless networks of the same RATs are available in an overlapping manner. For every RAT package, the proposed Algorithms 1 and 2 forms sub-packages based on parameters given in Equation (5). These sub-packages are ranked based on these parameters. These parameter’s changed values with SMD’s mobility are captured and stored in IEs and RANI. This change occurs periodically in our implementation, and we implement this using a link event of MIH (IEEE 802.21 Working Group & others, 2009).

The SMD prepares a list of candidate RATs by querying the nearest MiIS server, and fetches the RAT parameters. When SMD needs a RAT of an out-of-coverage wireless network, then SMD queries to the nearest MiIS server, and that server performs an intelligent broadcast within the group of all MiIS servers (IEEE 802.21 Working Group & others, 2009; Tseng et al., 2013). Any one or more MiIS server reply with RAT’s information to SMD through the SMD’s nearest MiIS server (IEEE 802.21 Working Group & others, 2009; Tseng et al., 2013). Every MiIS-server maintains a list of frequently accessed RATs and stores them into its cache to avoid further searching.

The proposed approach for hybrid RAT discovery captures the contents of IEs from the MiIS server by the conventional method of beacon and response frames (Altice, 2014; IEEE 802.21 Working Group & others, 2009).

Table 3. Contents of IEs.

| Generic IEs | Specific-PoA IEs |
|-------------|-----------------|
| Available RAT list and their operators | Location of POA |
| Agreements for SMD’s roaming among RATs | Bandwidth |
| Operational cost of RATs | PHY and MAC types |
| RAT security | Channel attributes for optimal link-layer connection |
| QoS | Upper layer service IEs specific to PoA |
Arkko et al., 2005). The first IE is the basic service set identifier (BSSID) of multiple APs/BSs. When a captured BSSID is the same for two or more APs/BSs, the received BSSID belongs to the same wireless network (WLAN/UMTS/Wi-MAX); otherwise, it belongs to different wireless networks. The SMD uses the second IE, RAT type, in RAT’s selection process to decide the type of network of APs/BSs. An IE, roaming-agreement among multi-RATs, is captured through MIIS server (IEEE 802.21 Working Group & others, 2009). A roaming-agreement among multi-RATs passes the authentication from serving-RAT’s AP/BS to the next candidate-RAT’s AP/BS. The authentication procedures and a pre-authenticated list of domain names implement the roaming agreement among visited wireless networks. The SMD captures a few IEs to know the capabilities of visited networks by broadcasting the management-beacon-frames or probe-reply-frames transmission through MIIS servers. A standard protocol known as access network query protocol (ANQP) is used between SMD and MIIS servers to exchange the messages (Altice, 2014).

### 3.4. Discovery and access selection process

Timely discovery and preferred RAT selection play a vital role in providing QoS and QoE to the end-users. We propose a discovery and access selection process (DASP) to discover and select a preferred RAT. The IEs captured through MIIS is used to discover a new PoA, as shown in Figure 3. We use 3GPP’s standard ‘access network discovery and selection function(ANDSF) (3GPP, 2014)’ in DASP which is supported by MIH’s NIST add-on (NIST IEEE 802.21 Addon, 2007) for ns-2.29 (NS, n.d.). The SMD queries ANDSF via MIIS servers to fetch IEs. The IEs contain VHO information as shown in Tables 3 and 2. The SMD finds an available RAT list, having mobility and routing policies of a particular area, with mobility management function and DASP, as shown in Figure 4. The SMD uses the selected RAT in heterogeneous wireless networks.

The discovered information of new PoA along with other parameters are input to the weighted RAT selection algorithm, as shown in Figure 3. The weights of parameters alter according to user preferences and requirements of an application. The algorithm returns the corresponding available interface and allocates the same to the application. The DASP is activated when:

![Figure 3](image-url). RAT Discovery and access selection process.
RSSI goes down below the threshold level.
The user initiates a video stream service request, which demands more bandwidth than the currently in-use interface.
The user preferences are modified, which gives new values of weights.
Vertical or horizontal handoff is unavoidable.

3.4.1. SMD structure to implement DASP
We propose an SMD’s abstract structure to implement DASP, as shown in Figure 4. The SMD consists of GUI, mobility management(MMF), DASP, applications and services, and network interface function(NIF). The MMF assists DASP in preparing the routing and mobility policies. User preferences are the input through the GUI of SMD, as shown in Figure 4. The NIF provides network drivers’ abstraction corresponding to wi-fi, UMTS, and Wi-Max to process user preferences. MMF and DASP handled the applications and services.

3.4.2. Multi-criteria selection function
A RAT selection process deals with multiple parameters in our proposed Algorithms 1 (HRD) and 2(ORRS). HRD and ORRS return an optimal rank of RATs using weights of multiple parameters. The multi-criteria function computes all RAT parameters’ cumulative weight, and the ORRS uses cumulative weight to return an optimal rank. Let W represents the cumulative weight for all considered parameters of a RAT. An individual parameter’s weight is w. P denotes the RAT parameters as given in Equation (5). The functions given in Equations (3) and (4) help in user’s preferred RAT selection.

\[
W = \sum_{i=1}^{n} P_i \times w_i \tag{3}
\]

\[
Rank_{RAT_j} = F(P, W) \tag{4}
\]

where n is the number of parameters in the jth RAT, w denotes a weight for the ith parameter of jth RAT. W depends upon the SMD’s distance from RAT’s BS/AP. The importance of individual parameters from the user’s perspective drives the weight w. The considered
multiple parameters (P) of RAT in our proposed approach are given in Equation (5).

\[ P = [RSS, SINR, HOF, BW, PL, PD, CP, MS] \]  

(5)

Where for each candidate RAT, RSS denotes the received signal’s strength; an SINR is a signal to noise ratio; HOF is the handover frequency; BW is the bandwidth; PL is the packet loss rate; PD is the packet delay; CP is the cost price according to the operator’s billing procedure, and MS is the mobility speed of SMD. Ranking of the RAT is done based on the \( W \), and the \( w \) specifies the importance of an individual parameter. The users provide the value of \( w \) for each parameter while moving with their mobile devices. The proposed approaches select a candidate RAT having the highest rank and begin a handover preparation further.

### 3.5. Hybrid RAT discovery and selection algorithms

Here we present algorithms that implement hybrid RAT discovery and optimal RAT selection. The proposed algorithms are given in 1 (HRD) and 2 (ORRS). These algorithms execute when a recent optimal RAT list is not available in SMD’s cache. The algorithms identify the SMD’s active interfaces using the \( \text{ifconfig} \) command. The HRD sends the SMD’s ID, location, and list of active interfaces for RAT discovery of SMD’s active interfaces to the nearest MIIS servers, as depicted in Figure 2. The nearest MIIS server consults the remaining MIIS servers in the group in a distributed way by broadcasting the SMD’s ID, location, and active interfaces; if it can not fulfill the SMD’s request. Next, HRD sends the captured RAT list to DASP by creating RAT packages and sub-packages using the IEs values if multiple RATs are present at the current location, and DASP initiates a handover process.

**Algorithm 1** Hybrid RAT Discovery Algorithm (HRD)

1. Start discovery timer(t)
2. Get the location(l) co-ordinates of SMD using GPS
3. activeInterfaces(al); \( al \leftarrow 3 \) \( \triangleright \) \( al = \{\text{wi-fi}, \text{UMTS}, \text{Wi-Max}\} \)
4. Fetch RANI of each RAT from IEs at nearby MIIS server
5. Input:ID, t, l, al
6. Output:RANI
7. procedure HRD (ID, t, l, al)
8. if (ID = true ≠ 0) then
9. \hspace{1em} for (i = 1; i ≤ al; i++) do \( \triangleright \) if SMD is authenticated
10. \hspace{2em} for each parameter i in IEs do \( \triangleright \) Get RANI for each interface
11. \hspace{3em} RANI\(_{\text{RAT}}\) = getIEs() \( \triangleright \) parameters as given in Equation (5)
12. end for
13. end for
14. else
15. \hspace{1em} call SMD authentication procedure
16. end if
17. if (RANI contains the updated values) then
18. Return RANI to ORRS for optimal RAT selection
19. else
20. \hspace{1em} call distributedDiscovery() at the nearest MIIS server and call HRD() again.
21. end if
22. end procedure

The proposed approaches prepare a preference RAT list according to RAT’s complementary features, ensuring that SMD switches over to a user-preferred RAT with desired QoS. Based on such features, our experiments use the RAT preference list as \( \text{wi-fi}, \text{Wi-Max}, \text{UMTS} \).
Algorithm 2 Optimal Rank-based RAT Selection Algorithm (ORRS)
1. activeInterfaces(al); ← 3
2. n ← number Of Parameters In RANI
3. Set W ← 0
4. Input: w, RANI
5. Output: Optimal Rank
6. procedure ORRS (W, w, n, al, HRD())
7. if (RAT = true) then
8. for (j = 1; j ≤ n; j++) do
9. for each parameter j in RANI do
10. W = W + j * w_j
11. end for
12. end for
13. for each value of i in al
14. RankRATi = W * P
15. sort(RankRATi[])
16. ORR ← RankRATi[0]
17. return ORR
18. end for
19. else
20. SMD does not support this RAT
21. end if
22. end procedure

3.6. GRA model for optimal RAT selection

RSS is a RAT’s basic parameter, and a RAT is selected only when its RSS is above the threshold value. Here, we do RSS-based modelling of optimal RAT selection by applying Grey Relational Analysis (GRA) Theory (Deng, 1989), to verify the proposed approaches mathematically. This problem’s nature is the reason to use GRA (Deng, 1989) to model the optimal RAT selection. Another reason for using GRA is that it uses a reference vector to be set by the user and compare it by the vector captured for each RAT (Deng, 1989). The Grey system theory’s biggest advantage, which makes it suitable for modelling our problem, is that it chooses RAT with QoS, which is closest to the expected by the user (Deng, 1989). The average-RSS at any point between an AP/BS and SMD decreases as a power law of distance from AP/BS (Rappaport, 2001). An average RSS of SMD at a distance \( D \) from AP/BS, is represented approximately by Equation (6) (Rappaport, 2001).

\[
\text{RSSI} = \text{RSSI}_0 \times \left( \frac{D}{D_0} \right)^{-N}
\]  

Here \( \text{RSSI}_0 \) is an RSS indicator at an arbitrary referred point, at \( D_0 \) distance away from AP/BS. \( N \) is an exponent for path loss. The typical value of \( N \) is taken from 2 to 4. According to Equation (6), \( \text{RSSI}_0 \) is considered at the nearest point from AP/BS, and with an SMD’s movement away from AP/BS, discrete RSS values are taken. Grey-relational-space(GRS) is defined as a binary-set which represents the mapping between the \( \text{RSSI}_0 \) and repeatedly taken RSSI values at discrete places (Deng, 1989). A GRS is represented as \( (\text{RSSI}, \Gamma) \) here \( \text{RSSI} = (\text{RSSI}_1, \text{RSSI}_2, \ldots, \text{RSSI}_k) \); forms a set of further taken \( k \) RSIS values at discretely referred places 1, 2, \ldots, \( k \). \( \text{RSSI}_0 \) is matched with such \( k \) values, and \( \Gamma = \text{GR map set} \).

If \( \gamma \in \Gamma \) then \( \gamma(\text{RSSI}_0(k), \text{RSSI}_0(k)) \) forms an image set at place \( k \) amongst all places from 1, 2, \ldots, \( n \), with a map set \( \gamma \) and \( \gamma(\text{RSSI}_0, \text{RSSI}_0) \) at all places with \( k = 1, 2, \ldots, n \), here
\( \text{RSSI}_0 = (\text{RSSI}_0(1), \text{RSSI}_0(2), \ldots, \text{RSSI}_0(n)) \quad \text{RSSI}_i = (\text{RSSI}_i(1), \text{RSSI}_i(2), \ldots, \text{RSSI}_i(n)) \)

Let \( \gamma(\text{RSSI}_0, \text{RSSI}_i) \) meets the requirements of Equation (7).

\[
\gamma(\text{RSSI}_0, \text{RSSI}_i) = \frac{1}{n} \sum_{k=1}^{n} \gamma(\text{RSSI}_0(k), \text{RSSI}_i(k))
\]  

(7)

then \( \gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) \) is called GR coefficient at a place \( k \) and \( \gamma(\text{RSSI}_0, \text{RSSI}_i) \) is called GR grade if and only if \( \Gamma \) is applicable on the axioms A1–A4, which are as follows:

A1: **Normal RSSI Interval**
\[
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) \in (0, 1] \quad \forall \ k,
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) = 1, \text{ iff } \text{RSSI}_0(k) = \text{RSSI}_i(k) \forall \ k
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) = 0, \text{ iff } \text{RSSI}_0 \notin \phi \text{ and } \text{RSSI}_i \in \phi \text{ here } \phi \text{ denotes a null values set.}
\]

A2: **Duality Symmetric RSSI Property**
\[
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) = \gamma(\text{RSSI}_i(k), \text{RSSI}_0(k))
\]

A3: **Wholeness RSSI Property**
\[
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) \neq \gamma(\text{RSSI}_i(k), \text{RSSI}_0(k))
\text{ iff } \text{RSSI} = \{\text{RSSI}_j | j = 0, 1, \ldots, n, \text{ and } n > 2\}
\]

A4: **Approachability RSSI Property**
\[
\gamma(\text{RSSI}_0(k), \text{RSSI}_i(k)) \text{ reduces with } \delta(k)
\text{ here } \delta(k) = [(\text{RSSI}_0(k) - \text{RSSI}_i(k))^2]^\frac{1}{2}
\]

The optimal RSS values satisfy the above axioms A1–A4. The use of multi-RATs is verified using GRA in terms of RSSI, and a verified RAT is selected amongst all to ensure Im-Ru.

### 4. Experimental setup and result analysis

The performance evaluation of the proposed Im-Ru framework through DASP using hybrid RAT discovery, and weighted-parameters based RAT selection Algorithms 1 and 2, is done through the trace data collected during the simulation on NS-2.29 (NS, n.d.) by using NIST mobility package (NIST, n.d.; NIST IEEE 802.21 Addon, 2007). NIST designed a package for testing the mobility using ns-2.29 by incorporating the wireless networks and MIH (IEEE 802.21 Working Group & others, 2009).

#### 4.1. Experimental setup

Figure 5 represents the considered heterogeneous wireless network scenario for the proposed RAT discovery and selection. This scenario also forms our simulation topology for the proposed approaches. In this scenario, we consider 3GPP and non-3GPP RATs. The non-3GPP and 3GPP RATs are wi-fi and Wi-Max and 3G(UMTS), respectively. This model’s application is in vehicular wireless communications for improved connectivity in infrastructure-based scenarios such as using roadside units or mobile infrastructure environment. We use wi-fi’s IEEE802.11b at the link layer to handle mobility. We design...
experimental set up according to the wireless network scenario shown in Figure 5. The collected trace data is analyzed on the given wi-fi parameters in Table 4, Wi-Max parameters in Table 5 and UMTS parameters in Table 6. Our topology consists of UMTS, wi-fi and Wi-Max cells. A single UMTS hexagonal cell with radius of 8000 m; three Wi-Max cells with radius of 1000 m, and seventeen wi-fi cells with radius of 100 m are deployed in the topology. The Wi-Max and wi-fi cells are placed in an overlapped fashion with UMTS cell, but the wi-fi and Wi-Max cells are placed in both overlapped and non-overlapped fashion. Only one SMD is considered for simplicity reasons, and because we are evaluating the process of RAT discovery and selection only. We can

![Image of wireless network model](image_url)

**Figure 5.** The wireless network model.

| Table 4. MAC layer parameters of WLAN. |
|----------------------------------------|
| Parameter                      | Value    |
|----------------------------------|----------|
| Default Scanning                | active   |
| PHY                              | DSSS     |
| Data Rate((Mbps))                | upto 54  |
| MAC Method                       | CSMA/CA  |
| Beacon Interval(s)               | 0.2      |
| Cell Radius (m)                  | 100      |
| Mobility Speed (m/s)             | 3        |
have multiple SMDs as well to evaluate the load balancing scenarios. Since we have targeted the applications from pedestrians to SMD’s vehicular speed, we considered the mobility speed of 3 m/s in wi-fi, 10 m/s in Wi-Max, and 25 m/s in UMTS cells. The parameters of wi-fi, Wi-Max and UMTS with their specified values according to the considered simulation topology are shown in the Tables 4, 5, and 6. We have considered video downstream traffic for different speeds of SMD in different cells. The UMTS parameters values are used according to the European Telecommunication Standard Institute (ETSI) standard (ETSI, 2015). The RAT discovery and selection are implemented with the help of information service hosted at the MIIS server. The ANDSF is accessed through MIIS servers hosted at AP/BS in the simulation setup to fetch the information stored in IEs (3GPP, 2014; Altice, 2014).

4.2. Performance analysis

This section evaluates our Im-Ru framework’s performance, which consists of hybrid RAT discovery and weighted-parameter-based RAT selection. We analyzed the results regarding packet loss, delay, and average throughput of coordinated utilization of SMD’s interfaces. The data collected from trace files generated during the simulation run is analyzed, and plotted graphs show the improved throughput compared to existing similar proposals. First, we run a simulation using ns-2.29 and MIH-enabled NIST mobility package without including the proposed approach’s code to compare our results. Next, the proposed DASP approach using Algorithms 1 and 2, is simulated using the NIST mobility package for downstream video traffic. We have compared our results with the work discussed by Abdullah et al. (2014), and El Helou et al. (2016) in terms of frequency of handover, packet loss, delay, average throughput, and preferred RAT selection time from the user’s perspective. According to the considered values of coverage radius and mobility speed of SMD in wi-fi, Wi-Max, and UMTS as given in Tables 4, 5, and 6, the minimum time taken to cross each cell is 33.33 s, 100 s, and 320 s respectively. Therefore, there is a chance of handover after this time if SMD

| Parameter                  | Value                     |
|----------------------------|---------------------------|
| Offered Bandwidth          | 2–11 GHz                  |
| data-rate(Mbps)            | 100                       |
| PHY                        | OFDMA                     |
| MAC Method                 | CSMA/CA                   |
| Cell Radius (m)            | 1000                      |
| Mobility Speed (m/s)       | 10                        |

Table 5. MAC layer parameters of WiMAX.

| Parameter                  | Value                     |
|----------------------------|---------------------------|
| Uplink’s bandwidth         | 1885–2025 MHz             |
| Downlink’s bandwidth       | 2110–2200 MHz             |
| Data-rate                  | 2 Mbps                    |
| Physical layer             | Frequency and time division duplexing |
| Cell radius (m)            | 8000                      |
| Mobility speed (m/s)       | 25                        |

Table 6. MAC layer parameters of UMTS.
moves with maximum specified speed. The proposed algorithms activate DASP after the times mentioned above or later in different cells if the SMD moves with its maximum speed in different network cells. This work finds the RAT’s preference order with the ‘technique order preference by similarity to ideal solution’ (TOPSIS) method (Hwang, 1981) to assign the user’s preferences. We use eight parameters as input to TOPSIS to determine individual RAT preference as given by Equation (5). The preferred RAT is selected based on the optimal rank of RATs. We evaluate proposed approaches’ performance and compare them with similar contributions regarding packet loss, packet delay, and average throughput for video down-stream traffic.

For video down-streaming applications, the considered size of a packet is 2500-bytes for the simulation. As shown in Figure 6, the lost packets are comparatively lower than bare NIST and PRMC based methods with the proposed DASP approach using HRD and ORRS algorithm. The main reason behind this improvement is the use of eight parameters, as given in Equation (5) in the rank calculation using the ORRS algorithm. The number of lost packets is almost at a stable level with the increase in SMD’s speed, as shown in the graph 6. This improvement in packet loss is due to RSS and SINR’s weights being higher in calculating RAT’s rank. The number of lost packets increases as soon as there is a handover from the current PoA to candidate PoA.

The packet delay depends on network congestion, more queuing time in the buffers of intermediate routers due to their limited processing power, and applied mechanisms. The larger value of the HOF parameter may lead to more packet delays. The packet delay is comparatively lower in our proposed approach, as shown in the graph shown in Figure 7. Again the rank calculation procedure minimizes the packet delay despite

![Figure 6](image_url). Packets loss of DASP as compared to NIST (NIST, n.d.) and PRMC (Abdullah et al., 2014) for video down-stream traffic.
some value of HOF. Initially, the packet delay values are similar for NIST, PRMC, and DASP, but DASP performs better after 45 s, and afterward, the delay lies consistently between 0.1 and 0.2 s.

Figure 7. Packets delay in DASP as compared to NIST (NIST, n.d.) and PRMC (Abdullah et al., 2014) for video down-stream traffic.

Figure 8. Average throughput of DASP as compared to NIST (NIST, n.d.), PRMC (Abdullah et al., 2014) and hybrid approach (El Helou et al., 2016) for video down-stream traffic.
We analyzed the performance of proposed approaches by taking an average of throughputs obtained from multiple simulation runs. The computed values of average throughput is compared with the NIST (NIST, n.d.), PRMC (Abdullah et al., 2014) and Hybrid Approach (El Helou et al., 2016) for video down-stream Traffic as shown in the graph 8. Initially, the average throughput is higher for all the proposed approaches because there is no handover. The DASP approach achieves a significantly higher average throughput compared to other existing approaches. The performance comes down with SMD’s higher mobility speeds (at 23 m/s) due to HOF’s larger value. Despite larger HOF, DASP performs better.

5. Conclusion
This paper showcased an Integrated multi-RAT utilization (Im-Ru) framework for multi-path computing applicable in 5G NR integrated access. The Im-Ru framework deals with the use-cases, having coexisting UMTS/WLAN/Wi-MAX RATs. The Im-Ru framework mainly consists of a hybrid RAT discovery and weighted parameter based RAT selection approach using HRD and ORRS algorithms. We have shown that Im-Ru approaches’ perform better in terms of average throughput and reliability by achieving lower packet loss and delay. The proposed approaches comprehensively cover a significant number of RAT parameters. The improved performance is due to the next candidate RAT’s timely discovery through the proposed hybrid RAT discovery model. The proposed RAT discovery model is not new; rather, we improved it by covering many RAT parameters. The RAT switches using IEs and RANI by initiating, planning, and executing VHO with MIIS’s help. The preference of RATs is according to ranks computed through the weighted-parameters-based technique. A RAT with the highest rank is selected. We analyzed the Im-Ru framework’s performance for SMD mobility at different speeds, from pedestrians to vehicular in wi-fi, Wi-Max, and UMTS RATs in terms of average-throughput improvement compared to some existing approaches and observed a significant improvement. We have observed that the Im-Ru approaches may help integrate the 5G-NR to the existing cellular and non-cellular RATs.

Note
1. https://ieeexplore.ieee.org/document/8975858, https://innovationqplus.ieee.org/resources/ieee-xplore-technology-landscape?lt=ieeexplorewidget

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No potential conflict of interest was reported by the author(s).

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