Smart BRT: Requirements for the Implementation of a Smarter Transport System

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***Abstract*—This paper proposes an infrastructure planning for Smart Bus Rapid Transit (BRT), focusing on network infrastructure requirements, and explores the essential elements for implementing a Smart BRT system. We discuss how network technologies, especially 5G and Wi-Fi, ensure continuous connectivity between buses, stations, and control centers. Moreover, we highlight the roles of Network Slicing and Edge Computing in managing data traffic and processing information. The article emphasizes that beyond adopting advanced technologies, the successful implementation of a Smart BRT demands strategic planning, public policies, and collaboration among various stakeholders, pointing towards a future where Smart BRT emerges as a promising solution for smart and sustainable urban mobility. Finally, we intend to comprehend and propose the scenarios considering a smart BRT and, in the future, could evaluate the system regarding some metrics and smart city criteria.**

***Index Terms*—Smart BRT, network infrastructure, 5G technology, Wi-Fi connectivity, smart urban mobility**

I. Introduction

Optimizing travel time in daily commutes is directly related to the means used to reach our destination, highlighting traffic and its impact on daily activities. Population growth and the increase in personal vehicles in large urban centers, combined with disorderly growth and lack of structural planning, lead to chaotic scenarios that directly impact people's mobility [1].

Public transportation is an efficient and sustainable alternative, where the *Bus Rapid Transit* (BRT), for example, is a flexible and low-cost solution that prioritizes the use of segregated lanes, has level boarding, with prepaid fares, along with other components that significantly differentiate it from traditional urban buses [2]. Furthermore, technological advancements have provided significant opportunities to enhance public transportation systems, such as the BRT.

Another important factor that has become essential in modern society is connectivity [3]. Today, we have a ubiquitous environment, mainly due to the high penetration of mobile devices and the use of technologies such as the Internet of Things (IoT), with sensors and connected devices collecting data in real-time, directly assisting in optimizing routes, public transportation, and safety in urban roads [4].

Smart BRT emerges from this scenario as an innovative system, incorporating advanced traffic management, information on vehicle health and safety, and assisting in accident prevention and proper functioning. It can offer users more confidence and comfort, with access to always up-to-date travel information, entertainment during the trip, and payment options, transforming this transport choice into a pleasant experience and promoting integration between different modes of transport, such as subway, trains, bicycles, and regular buses, playing a crucial role in the advancement of smart cities. This system represents a significant step towards improving urban mobility, reflecting the commitment to creating smarter and more adaptable transportation infrastructures to the dynamic needs of modern cities.

This article offers a high-level view on using mobile networks in public transport to provide better quality and comfort in mobility services in large urban centers, focusing on a Smart BRT system. The main objective of this article is to present an infrastructure that benefits both system managers and users, offering real-time information to enhance the system's safety, maintenance, reliability, comfort, and convenience.

Among the main contributions of this article are:

- An overview of a BRT system;
- The current panorama and state of the art on the use of mobile networks for communication and management of BRT systems;
- Definition of a Smart BRT system and its advantages and challenges;
- A planning model for the deployment of a Smart BRT system, defining the components necessary for its operation;
- Proposal for applying the Smart BRT model to a real environment.

The subsequent sections of this article are organized as follows. Section II presents related works and their main differences compared to what is proposed in this article. Section III presents the fundamental concepts for understanding this article, including public transportation systems, urban mobility, and mobile networks. Section V presents the proposed deployment model for the Smart BRT and how it relates to the necessary network technologies through two application scenarios. Section VI presents the main challenges for the deployment of the proposed model. Finally, Section VII encapsulates the conclusions and final considerations.

II. Related Works

Intelligent transportation systems have been widely discussed in recent years. Many researchers have evaluated their main characteristics and practical applicability, especially in autonomous systems and smart cities.

In [5], the authors proposed a Smart BRT system aimed at providing an efficient, accessible, and sustainable transportation option for the community of the *Institut Teknologi Sumatera* (ITERA) in Lampung, Indonesia. Through a case study, they analyzed the transportation preferences and needs of the community. The authors also explored the operational aspects of Smart BRT, including route planning, fares, and operational costs. Furthermore, they discussed the impacts on carbon emissions and the main challenges and opportunities in implementing the system.

In the study by [6], researchers used Arduino UNO microcontrollers connected to buses, equipped with GPS and infrared (IR) sensors on the entry and exit doors, and with Bluetooth communication. These devices connected to a cloud server, while an Android app allowed users to monitor the bus location, the number of available seats, and information on itineraries and routes. Using K-means Clustering Algorithms and Estimated Time of Arrival (ETA) calculations, the authors established the appropriate bus frequency and estimated their arrival at destinations.

In [7], a comprehensive study developed a performance model for BRT systems using hierarchical models based on Continuous Time Markov Chains (CTMC), capable of identifying peak intervals for efficient travel times and the impact of system failures on performance. Furthermore, in [8], a Stochastic Petri Net model evaluates BRT systems' performance, focusing on metrics like average system size, queue length, waiting time, and the probability of a user missing the bus, creating scenarios with varying departure intervals and the number of vehicles on the BRT system route.

Researchers in [9] focused on the integration of public bus transportation systems into urban and intelligent vehicular networks, where the bus plays a central role as a service provider in these networks. They addressed applications such as service swapping, delay-tolerant and opportunistic networks, authentication, and in-vehicle services for passengers.

In [10], the authors presented a tutorial on the use of 5G technology in-vehicle communication and interaction. They described the requirements for vehicular communications and evaluated existing standards and their limitations. They related the 5G architecture with promising characteristics for vehicular communications, offering a comprehensive view of how 5G technology can transform vehicle communication, enhancing safety, efficiency, and connectivity in urban and transportation environments.

Finally, in [11], the authors discussed trends in ITSs, focusing on creating a connected environment for smart mobility. The paper offers a comprehensive perspective on ITSs, the use of AI techniques, and cybernetic sources applied to smart cities, focusing on monitoring and managing transportation systems. Moreover, they address the connection between vehicles, infrastructure, and pedestrians, which is essential for the future development of ITSs.

Tabel I emphasizes the differences between the previous works and, with this proposal, envisioning a Smart BRT system that provides adequate network infrastructure for the effective use of resources. The contribution of this article applies to areas where previous studies have shown gaps, highlighting facilitating mechanisms for implementing a Smart BRT system.

Work	**Proposes Methodology**	**Applicable Technologies**	**Real Scenario**	**5G/Wi-Fi Parameters**
This Paper	X	X	X	X
Z. F. Saraswat et al., [5]	X	X	X	
A. J. Kadam et al., [6]	X	X	X	
2019 R. Dantas et al., [7]	X	X		
2021 R. Dantas et al., [8]	X	X	X	
F. Modesto and A. Boukerche [9]	X	X	X	
S. A. A. Shah et al., [10]	X	X	X	
A. Sumalee and H. W. Ho [11]	X	X	X	

TABLE I
COMPARISON OF DIFFERENT WORKS

III. Theoretical Framework

This section presents the main concepts necessary for understanding this article.

A. Bus Rapid Transit - BRT

BRT is a bus-based rapid transit system designed to provide users with comfort, reliability, and economy [12]. Moreover, it can offer capacity equal to that of a metro, with the difference of having a low cost and greater ease of implementation compared to trains, as it has high flexibility and scalability [12].

The BRT standard establishes five essential elements for its operation: (i) segregated lanes; (ii) stations aligned with street centers; (iii) off-bus fare payment; (iv) level boarding; and (v) priority at intersections [13].

According to [14], BRT is present in 188 cities around the world and has approximately 5,712 km of total length. This system is responsible for the daily transport of more than 31 million passengers per day, with Latin America being the region that uses this means of transport the most. Brazil leads the usage indicators on the continent, while Bogotá, Colombia, presents the most successful BRT utilization model among South American countries.

B. Smart BRT

ICTs (Information and Communication Technologies) are fundamental components for a high-standard BRT system designed to serve a large volume of users. Such technologies should provide agile, accurate, and reliable services, covering financial transactions, personal information transmission, and real-time operational systems [13].

Advances in ICTs have allowed systems to expand their capacity for autonomous, efficient, and connected data collection, analysis, and use. We call this evolution smart technologies [15].

The adoption of smart technologies by BRT systems can drive improvements in operational efficiency and passenger experience, as well as provide high-quality services [16]. Among the main services included are electronic payment systems, intelligent signaling, and traffic control, advanced passenger information systems, GPS monitoring and telematics, automotive security systems, predictive maintenance, connectivity, and vehicle-infrastructure communication [16].

IoT plays a transformative role in the Smart BRT context, enabling communication between devices without human intervention. This technology has been widely used in sectors such as health, transportation, and the automotive industry [17]. Characterized as a dynamic global network that is self-configuring, IoT connects physical objects—vehicles, devices, or other equipment—through advanced electronic components, integrated circuits, specialized software, and ultra-sensitive sensors, in addition to robust network connectivity [17]. This configuration enables the efficient acquisition and exchange of real-time data, allowing for optimization of operational processes and continuous innovation, which are premises for a Smart BRT system [6].

Just like IoT, another essential technology for building and maintaining a Smart BRT system is ITS (Intelligent Transportation Systems). It consists of information technology, communication, and control applications aimed at enhancing the efficiency, safety, and sustainability of transportation systems [18]. In ITSs, sensors are responsible for collecting traffic and vehicle data, and these data are processed in real-time and transmitted through communication technologies, such as Dedicated Short-Range Communication (DSRC) and Intelligent Transportation Systems using 5G Technology. ITSs have various applications, such as vehicle location, Public Transport Priority System (PTPS), and road Information provision, among others. [19].

C. Communication Technologies for Smart Things

For the BRT System to function as Smart BRT, the incorporation of various technologies is essential, working together to optimize its operations and provide users and system managers with the desired potential. Among the communication technologies that enable this project, the following stand out:

Positioning System - a satellite navigation system that provides precise location and weather information from anywhere [20]. Using GPS modules on buses allows for real-time vehicle tracking, including location systems that use the cellular network for more accuracy, such as Assisted GPS (A-GPS), providing information that can assist in arrival predictability and fleet monitoring.

5G Connectivity - 5G networks stand out for their exceptional connection capability, allowing for efficient interconnection between mobile devices and a wide range of other equipment [21]. The 5G network infrastructure can work with different frequency bands, managing bands from 6GHz and above 24 GHz. The spectrum band influences the range and capacity of the network, as seen in TableII. The fifth generation of mobile networks allows for more efficient communication between devices, regardless of location.

There are three main categories of services in 5G networks: *Enhanced Mobile Broadband* (eMBB), *Ultra-Reliable Low Latency Communication* (URLLC), and *massive Machine Type Communication* (mMTC). The eMBB aims to improve the mobile broadband experience, offering higher capacity and speed. The URLLC focuses on highly reliable and low-latency communications, crucial for real-time applications. The mMTC addresses the massive connection of devices for the Internet of Things (IoT), ensuring energy efficiency and reducing signaling overhead [21].

Wi-Fi Networks and the IEEE 802.11 standard - Wi-Fi networks can provide connectivity to passengers and the fleet monitoring and management systems in stations and buses of the Smart BRT system, also working complementarily to 5G networks.

Vehicular Networks (*Veicular Ad Hoc Networks* (VANETs)) - a subtype of network designed for communication between vehicles, developed to support fast mobility environments, like those found in intelligent transportation systems (ITS), enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [22].

VANETs use technologies such as the IEEE 802.11p standard, derived from Wi-Fi but adapted for dedicated short-range wireless communication. The use of VANETs in a Smart BRT system is crucial for supporting safety, acting with collision alert systems, intelligent traffic control, real-time traffic information, and other services aimed at improving safety and efficiency on the roads [22].

The foundation for deploying a Smart BRT is a robust connectivity infrastructure with the high bandwidth necessary to manage the various data demands generated by the system and its users.

IV. Services and Applications of a Smart BRT

Electronic Payment Systems - The use of contactless payment, such as smart cards or mobile apps, speeds up boarding and alighting. For a truly positive passenger experience, systems that reduce transaction time and increase security and ease of use of interfaces must be considered.

Mobile Apps, Information Platforms, and Onboard Entertainment - provide accurate real-time information about schedules, routes, traffic conditions, and system updates, contributing to a better public transport user experience, with access to clear and easily understandable information, which can be remotely or locally accessed. Onboard entertainment can be provided through screens with advertisements and useful information, as well as internet access for passenger entertainment.

Monitoring and Security - Systems with security cameras and emergency alerts inside buses and at stations improve safety; cameras may use facial recognition technologies, and vehicles should use tracking technologies that allow moni-

TABLE II
DISTINCTIONS BETWEEN SPECTRUMS

Spectrum	Low Band	Mid Band	High Band
Frequencies	600 MHz 700 MHz 850 MHz	2.0 GHz 2.5 GHz 3.7 GHz	24 GHz 27.5 to 31 GHz 37, 39, 47 GHz
Cell Range	Up to 40 km	Up to 19 km	Up to 600 meters
Coverage	Wide	Moderate	Limited
Capacity	Low	Medium	High
Location	Rural, Suburban and Urban	Suburban and Urban	Urban and Densely Urban

toring at all times. These systems will be integrated into a monitoring center for fleet and station management.

Traffic Control and Signaling Systems - Effective traffic coordination ensures the continuous flow of buses. These technologies can be used to prioritize the movement of BRT vehicles at intersections and the duration of the green signal, ensuring a reduction in travel time and the number of stops, reflecting positively on the punctuality of the service.

Renewable Energies and Energy Efficiency - Considering renewable energy sources for BRT vehicles and implementing technologies that optimize energy efficiency contribute to the system's sustainability.

A. *Support Systems and Technologies for Smart BRT*

Edge Computing (*Mobile Edge Computing* (MEC)) - MEC technology decentralizes data processing, bringing analysis and decision-making closer to the point of use, resulting in ultra-low latency and high bandwidth, ideal for real-time applications [23]. In the context of a Smart BRT system, MEC can be used to process information locally on buses or stations, such as real-time security and monitoring systems.

Network Slicing - the division of a physical network infrastructure into independent virtual networks, each configured to meet specific service, application, or user requirements. Slices offer dedicated resources, such as bandwidth and latency, optimizing resource use and enabling the creation of differentiated service offerings [24].

In a Smart BRT system, the strategic use of slices provides an effective approach to managing different types of data traffic, covering areas such as monitoring, security, entertainment, and video surveillance.

V. PROPOSED SMART BRT MODEL AND DEPLOYMENT SOLUTIONS

Efficient integration of various technologies is essential for implementing a Smart BRT system. Figure 1 depicts the smart BRT systems that represent the infrastructure communication and securing the availability of necessary resources to capture, process, and transmit data generated by the system. In this section, we will explore existing communication technologies that can support Smart BRT, presenting the advantages and challenges of each type of infrastructure through two scenarios: 5G Mobile Networks and Hybrid Communication Infrastructure (with 5G and Wi-Fi Networks).

A. *East/West System Infrastructure*

We consider a dense urban environment, as we are dealing with a transport system used by many users, approximately 63,000 passengers on weekdays, located on extremely busy roads, with six available lines [25]. The East/West line of the BRT System of Greater Recife is a city in the Northeast Region of Brazil.

The East/West **Via Livre Corridor** has a length of 12 kilometers, with 19 stations, four of which are integration stations that can interact with other means of transport, such as trains and the metro, and two integration stations with the North/South Via Livre Corridor. The other stations are intermediate and are located in the middle of the segregated road. The stations are, on average, approximately 500 meters apart each other [25]. Table III presents some general data regarding the BRT East/West Corridor.

TABLE III
BRT SYSTEM DATA

Parameter	**Value**
Trips per Weekday	526
Buses in Operation (Peak Hour)	26
Passenger Capacity per BRT Bus	160
Peak Hour (6:59 AM - 7:59 AM)	
Total Passengers at Peak Hour (Approx.)	6,300
Passengers per Bus per Trip (Avg.)	242

In total, 26 buses are in transit at peak hour [26]. We estimate that 10% of the total passengers (6,300 people) uses the East/West Corridor and are in transit between stations. Assuming passengers embark and disembark between stations along the route, this implies an average of 242 users per bus per trip.

B. *Scenario I - Communication Infrastructure Based on 5G Mobile Networks*

A 5G tower signal can reach a distance of up to five kilometers, and the number of antennas per base station (BS) can vary from 32 to 256 [27]. Moreover, the density of a macro cell is 40 to 50 BS/km² [27], with a coverage of 8 to 30 kilometers, capable of accommodating more than 2,500 users.

Using smaller cells supports 5G in increasing the overall network capacity. A 5G Small Cell ranges from 15 to 600 meters and is usually installed on external infrastructures like light poles but can also be placed indoors. The installation location varies depending on the type of service desired in a specific area. Small cells accommodate 100 to 2,000 users.

Based on the East/West Via Livre scenario, considerations such as selecting the 5G spectrum, implementing macro and small 5G cells, equipment promoting connectivity in BRT

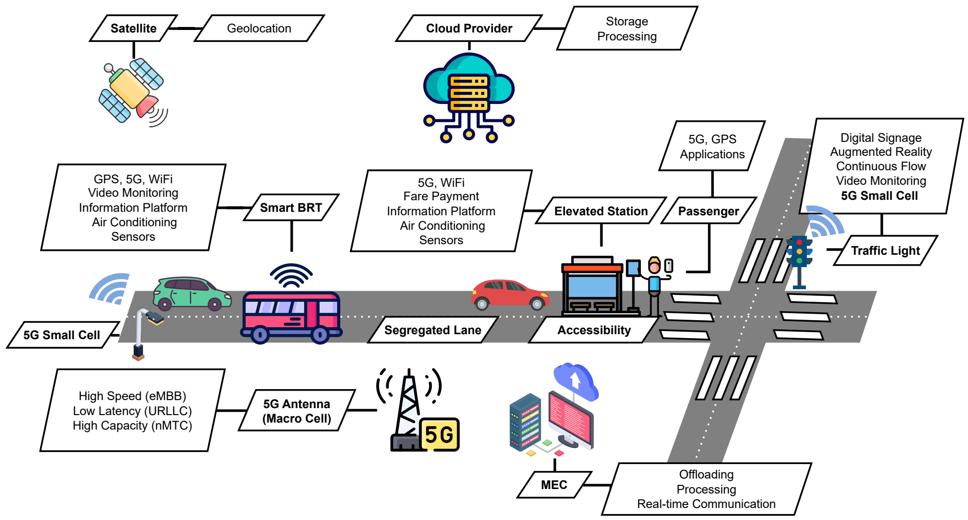

Fig. 1. Hybrid Infrastructure of a Smart BRT

vehicles, network backhaul, network management and monitoring systems, and support systems are necessary.

As the scenario is of high urban density, combining mid and high bands can offer a balance between range, capacity, and high transmission capacity.

Based on [28], which utilized the 3GPP TR 38.901 standards, we can calculate the number of gNodeB base stations in a cellular network required to cover the East/West corridor using Equation 1.

$$N_{gNodeB} = \frac{A_T}{C_A} \tag{1}$$

where A_T is the total area of the surface, and the coverage area (C_A) can be calculated using Equation 2.

$$C_A = 2.6 \cdot (d_{2D})^2 \tag{2}$$

where $(d_{2D})^2$ is the cell radius, and the constant 2.6 is determined for a three-sector model.

To serve the East/West corridor, based on the equations, the required number of sites is 649.74, considering C_A of 18,468.81 m², which was calculated for the LOS scenario with a cell radius of 135.9 m².

To ensure higher network capacities and directly impact the quality of the connection, the appropriate choice of backhaul infrastructure makes a significant difference in this project. Usually, backhaul for macro cells is achieved through fiber optic to the main network.

Vehicles must feature 5G compatible communication technology, ensuring connectivity to allow real-time acquisition of information such as tracking, travel information, support for electronic payment systems, video surveillance, sensing, and other IoT applications. Stations also need to have 5G compatible communication technology.

Another important aspect is having a centralized management system, monitoring the network, and managing and separating data traffic. Network slice technology collaborates in network management, allowing dedicating slices for different applications, helping to ensure system flexibility and information security.

C. Scenario II - Hybrid Communication Infrastructure

Another proposal is to use both technologies (Wi-FI and 5G networks). Although there are similarities, 5G and Wi-Fi are usually used in different contexts, with 5G related to mobility and Wi-Fi for local use. Implementing a Smart BRT project based on a hybrid communication infrastructure using 5G and Wi-Fi networks requires 5G coverage along the road and Wi-Fi connectivity.

A potential scenario involves using 5G macro cells along the road, at least 8 of them, aided by 24 5G small cells per kilometer, especially at BRT stops and stations, helping to increase signal density and capacity in these high-demand areas.

BRT vehicles and stations would be equipped with Wi-Fi routers to provide connectivity, assisting passengers in connecting to a free network while using the system and enhancing the experience through internet access. Additionally, users would have access to travel information, entertainment, and electronic payment systems.

The backhaul would need robust infrastructure to connect the 5G cells and Wi-Fi access points to the internet backbone. Fiber optics and wireless backhaul could be used for this purpose.

A critical point of using hybrid infrastructure is integrating and managing the network, where a central management model is advised to coordinate and monitor the interaction between 5G and Wi-Fi networks. Security strategies like virtual private networks (VPNs) and other protocols can protect communication and data.

VI. Challenges

Implementing a Smart BRT system requires a robust and reliable network infrastructure that is scalable and flexible, meeting the high-speed and low-latency requirements of 5G. It should also allow interoperability among different systems and technologies, including unified communication standards, to enable integration with other modes of transportation and urban systems.

Ensuring rapid and effective communication between vehicles, stations, and the BRT's central control systems poses another challenge. Additionally, mobility management is directly impacted by the large volume of data generated by passengers, real-time vehicle monitoring, and their sensors, as well as the organization, processing, security, and data protection. These characteristics imply the need for continuous and reliable connectivity to prevent failures that affect service efficiency and passenger safety.

Other potential challenges in building the Smart BRT include adopting new technologies, strategic planning, public policies, and collaboration among various stakeholders, including governments, transport operators, network operators, and the community.

VII. Conclusion

This article explored the requirements for implementing a Smart BRT system, focusing on network infrastructures. 5G and Wi-Fi networks were identified as fundamental components to ensure efficient and continuous communication in Smart BRT.

The ability of 5G networks to provide high-speed and low-latency connections is crucial for real-time operations. In contrast, Wi-Fi networks offer an effective solution for local connectivity on buses and stations. These technologies form the backbone of the Smart BRT's communication infrastructure, enabling real-time information exchange between buses, stations, and the control center.

Moreover, adopting technologies like Network Slicing and Edge Computing helps efficiently manage various data traffic types and their local processing. These technologies also contribute to user security and privacy, important aspects of modern public transport systems.

The success in implementing a Smart BRT system is linked to the ability to establish an integrated network infrastructure. This infrastructure must be capable of supporting various technologies and applications. With the continuous evolution of network technology and collaboration among different stakeholders, Smart BRT presents itself as a promising solution for the future of urban mobility.

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