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Practical Application of Mesh Opportunistic Networks

Miguel Ángel Martín-Pascual [1,2,*] and Celia Andreu-Sánchez [2]

[1] Technological Innovation, Instituto RTVE (Corporación RTVE), Sant Cugat del Vallès, 08174 Barcelona, Spain
[2] Neuro-Com Research Group, Audiovisual Communication and Advertising Department, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, 08193 Barcelona, Spain; celia.andreu@uab.cat
* Correspondence: miguelangel.martin@rtve.es

Abstract: Opportunistic networks allow for communication between nearby mobile devices through a radio connection, avoiding the need for cellular data coverage or a Wi-Fi connection. The limited spatial range of this type of communication can be overcome by using nodes in a mesh network. The purpose of this research was to examine a commercial application of electronic mesh communication without a mobile data plan, Wi-Fi, or satellite. A mixed study, with qualitative and quantitative strategies, was designed. An experimental session, in which participants tested opportunistic networks developing different tasks for performance, was carried out to examine the system. Different complementary approaches were adopted: a survey, a focus group, and an analysis of participants' performance. We found that the main advantage of this type of communication is the lack of a need to use data networks for one-to-one and group communications. Opportunistic networks can be integrated into professional communication workflows. They can be used in situations where traditional telephones and the Internet are compromised, such as at mass events, emergency situations, or in the presence of frequency inhibitors.

Keywords: opportunistic networks; OppNet; mesh communication; mobile communication

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Citation: Martín-Pascual, M.Á.; Andreu-Sánchez, C. Practical Application of Mesh Opportunistic Networks. *Appl. Syst. Innov.* **2023**, *6*, 60. https://doi.org/10.3390/asi6030060

Academic Editor: Luca Mainetti

Received: 22 April 2023
Revised: 5 June 2023
Accepted: 13 June 2023
Published: 16 June 2023

1. Introduction

As a hyperconnected society, there are occasions when communication networks fail and data access is impossible through conventional means, highlighting the strategic importance of alternative electronic communication methods. Natural disasters cause the collapse of communication towers and Internet services [1,2]; very crowded areas, such as concerts or sports events, affect users' communications; and areas with few inhabitants need expensive investment for regular communication. It has become clear that social networks have become useful to cover disasters and emergencies [3,4] and connect people. However, in many circumstances, it is very possible that we will be left without access to these networks, the Internet and even, possibly, mobile telephone communications, limiting their utility.

On the basis of finding alternatives to electronic communications without a mobile data plan, Wi-Fi or satellite devices, this study explores Electronic Opportunistic Networks (OppNets) usage on task performance via a perceived task structure under diverse communication flows. This study aimed to address the following research questions:

- RQ1. What are the benefits and limitations of mesh OppNets in one-to-one communication compared with current alternatives?
- RQ2. Can mesh OppNets be used for successful group communications?
- RQ3. Can mesh OppNets be integrated in a professional communication workflow?

To obtain answers, we conducted an experimental study by applying opportunistic mesh network communications between 14 participants in different communication workflows, including one-to-one communication, group communication, and communication in a professional journalism context.

2. Theoretical Background

2.1. Opportunistic Networks or OppNets

Opportunistic networks or OppNets, and specifically local mesh networks, have been seen to be very useful in emergency situations [5]. The term OppNets was coined by Leszek Lilien in 2005, thinking of mobile seed networks that can expand locally and be deployed, for example, for communications after an earthquake [6,7]. An opportunistic mesh network allows for direct communication between mobile devices that are within reach, which can be called nodes, even if there is no cellular or Wi-Fi coverage. The OppNet mesh network uses intermediate nodes to send messages from their sender (or source) to their receiver in an opportunistic way [8]. To do this, low-energy connections can be used to establish personal wireless networks that connect mobiles and their data screens to portable mesh radio devices, for example, using Bluetooth protocols. These networks were originally conceived and designed for emergency situations where no alternative stable telephone communication is available. However, the concept transcends its use for emergencies, and facilitates the use of a free public radio spectra for social, interpersonal, and community communications outside of data networks, Wi-Fi networks or other means to access the Internet [9]. The mesh network can grow and be strengthened by adding new nodes, represented by mobile users and their OppNet devices, and is likely one day to become integrated into the mobile device itself. Obviously, no manufacturer or operator is currently interested in offering inexpensive equipment that bypasses data tariffs and the control of large portals, permitting private communications independent of the data giants and with no need to pay an operator fee.

In a typical mesh OppNet scenario, the individual uses their mobile device (without network connection) as a screen, linked to an OppNet radio device that sends the desired information and that simultaneously acts as a node to receive information from others (see Figure 1). Thus, mesh OppNets are networks in which the nodes may be individual users, vehicles, fixed devices, etc. [10]. The more users in the mesh OppNet, the more nodes, and the more nodes, the greater the scope for communication and coverage. This means that the coverage provided by mesh OppNets varies in time and space depending on the density and mobility of the users with devices.

As a society, we now assume that mobile media can be characterized not by its technological convergence but rather, by its network organization [11]. However, this network articulation tends to refer to the content and its distribution. By contrast, mesh OppNet communication between people and small communities can also occur according to this model of network organization. Accordingly, mobile media, communication studies, and electronic commerce must consider these emerging technologies, in parallel to the extension of smartphones, which will have important consequences for community and social communications, and in territorial management [12].

2.2. The Coverage and Scope of the Mesh OppNets

As mentioned above, the coverage of these networks depends on the nodes that exist. Each device not only serves as a sender and receiver of its own communication but is also a node for the transmission of external communications. Considering that the range of these devices is usually a radius of around 4000 m, knowing how many users are around will give us information about the potential coverage we can obtain from our network. Thus, mesh OppNets represent a mode of communication with a scope that is dictated by the number and location of the other users (or nodes). For example, when the distribution of perhaps the most widely implanted device is studied, the goTenna Mesh™ device (see Figure 2), a disparity in implantation can be observed over the geographic area of interest with consequent differences in potential coverage. In areas such as California, Florida or New York, the coverage of this device is extensive due to its high density, whereas in areas such as northern and southern Europe, the absence of nodes (or repeating goTenna devices) makes widespread territorial coverage impossible. In the coming years, we are likely to witness an emergence of these small devices, as they are currently being developed by numerous start-ups. At present, there are a few similar commercial devices registered, such as Garmin inReach, SPOT X Satellite Messenger, Beartooth (the most similar to goTenna Mesh), Fogo or Sonnet, but they still do not have the diffusion of goTenna Mesh. Sonnet is a little delayed in its development and was not commercialized in 2023, despite being announced for 2019. All these mesh OppNet devices are priced between $45 and $300, depending on their GPS characteristics, whether they have a screen or use of the mobile phone's screen, and their autonomy or coverage [13]. It should be remembered that at least two devices are required to establish a mesh network and indeed, they are commonly sold in pairs. In these cases, the mesh network is meaningless if there are no devices to create it.

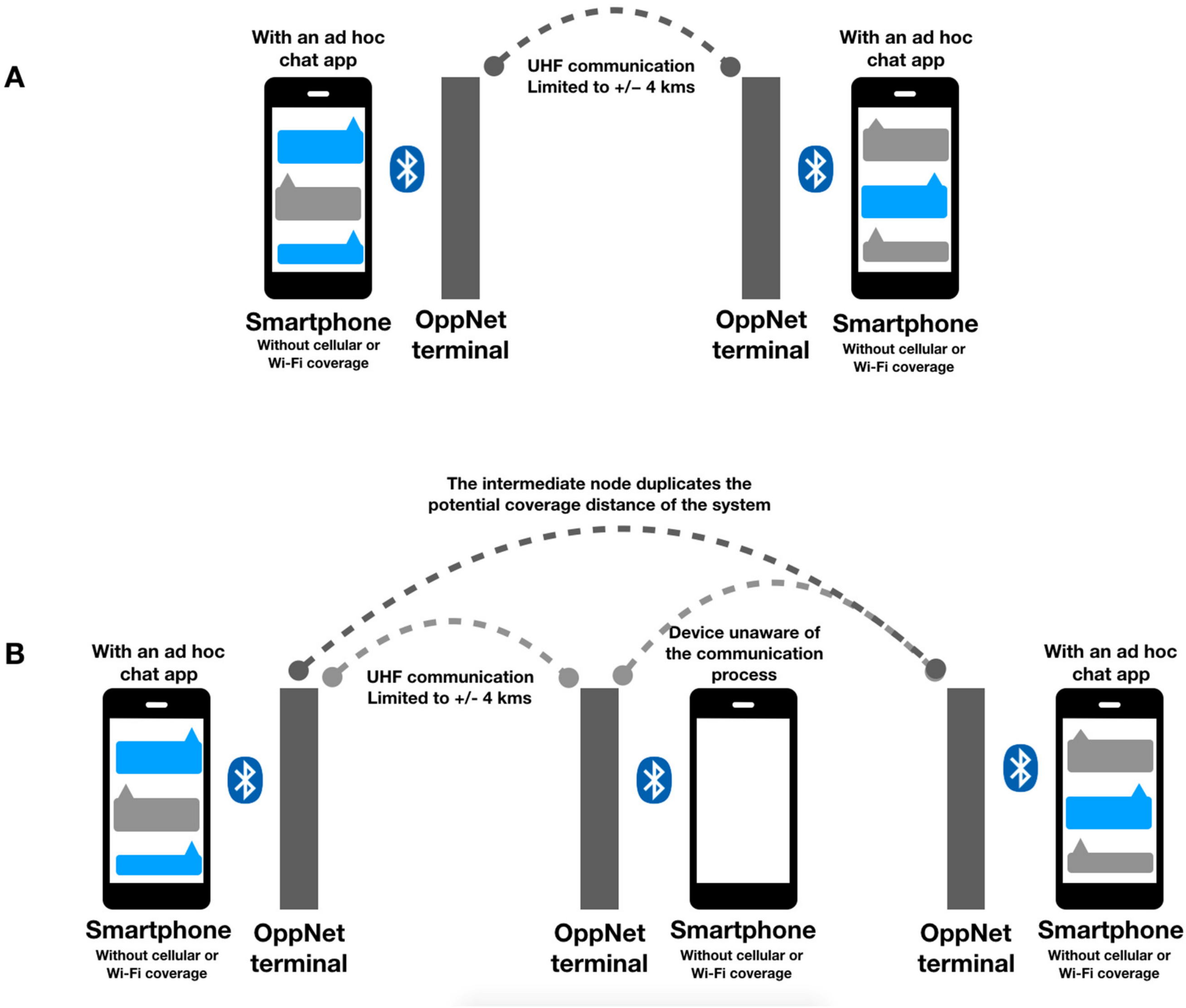

Figure 1. Typical OppNet communication protocol with common devices in a mesh network: (**A**) One-to-one and direct communication; and (**B**) one-to-one communication using a third-part node to increase the distance covered by the system. Note that the intermediate node is unaware that it is being used for the communication process.

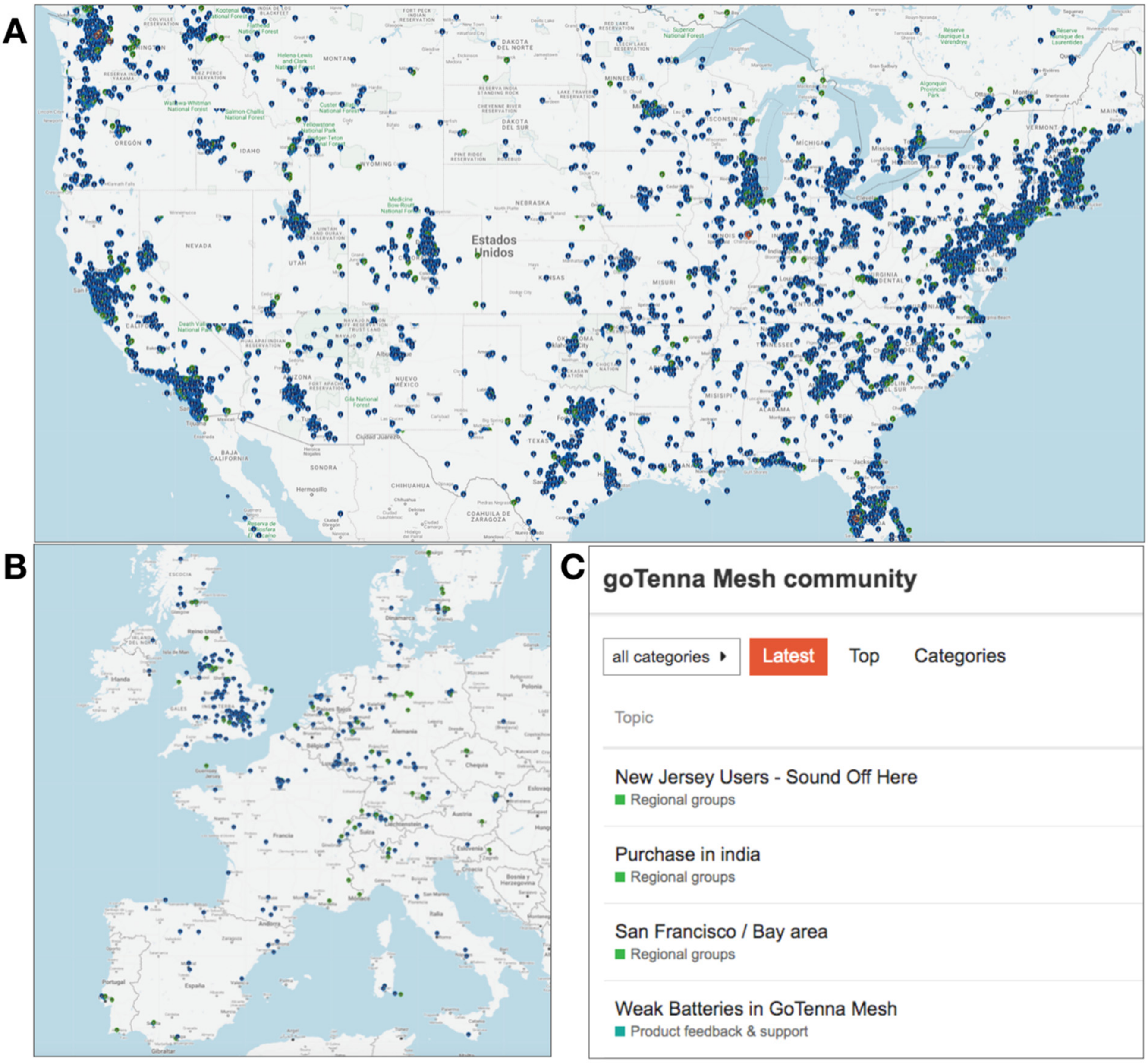

Figure 2. Implementation of goTenna Mesh devices (April 2023) in: (**A**) U.S.; (**B**) in part of Europe. This is not exhaustive as only publicly communicated nodes appear; and (**C**) regional groups of this system where users discuss ideas and issues. Note that we cannot know the use given to these devices. Source: https://imeshyou.gotennamesh.com/ (accessed on 6 April 2023), courtesy of goTenna Mesh Support.

2.3. Privacy and Security in Mesh OppNets

The privacy and security of personal messages are among the most important things that interest users, companies, and public administrations today. We know that, through automated processes that use more or less biased algorithms, our connected society accumulates digital dossiers of people online [14]. The problem with this is not simply the loss of control over personal information, the existence of "proto big brother" controllers, or omniscient corporations or portals but rather, the problem is the bureaucratic processing of uncontrolled data that affects our lives [15], constituting an authentic digital tattoo [16–18]. In this sense, mesh OppNets involve interactions among multiple decentralized nodes [19], not in terms of a social network but rather, through mesh networks that establish opportunistic connections that can occupy the urban space. These communication networks do not require formal leadership, or a command post or control center, nor do they require a vertical organization responsible for distributing information or instructions. Rather, these systems advocate networking as a way of life [19]. In this context, this type of network offers new options in terms of the privacy and security regulations of personal communications.

Although there does not currently seem to be an appropriate approach to these situations, it is understood that regulating mesh OppNets should take place within the framework of the unstoppable phenomenon of convergence between the information and communications technologies [20]. Such approaches must align with the new discipline of computer law, which assumes the right to computer freedom as a personal modality recognized by citizens, legally protecting the "computer identity" of each individual [21]. Alternatively, mesh network proposals are emerging, such as payment gateways for Bitcoins using Blockchain or other cryptocurrency transactions, employing protocols with decentralized networks [22]. Without a need for the Internet, these mesh OppNets protocols mask the physical situation of the sender or receiver, and they avoid telephone identification as they do not use a SIM card or IP address [23,24].

2.4. OppNets and Broadcasters

To date, too little attention has been paid to ad hoc electronic communications and opportunistic networks (or OppNets) in professional settings, outside of security services [25]. Broadcast work in crowded environments, saturated with terminals, a lot of noise, at large events or in places with a complicated orography, places important demands on efficient electronic communications. During the coverage of large events, such as demonstrations, events in stadiums, circuits, outdoor sports, concerts, fairs, etc., coordinating intercommunications is decisive. Recently, this problem has been aggravated by live mobile journalism (MoJo) broadcasts through dedicated Wi-Fi and data networks, especially when connected multi-camera or mobile streaming techniques are employed [26]. For audiovisual retransmissions of such events, it is best to free up the network as much as possible and not to use the entire data bandwidth, directing or sending data to servers for team communications or coordination. In addition, these are often very noisy environments that reach saturation due to the high density of people connected or the difficulties in obtaining a connection that allows for broadcast-quality streaming. Indeed, it is possible that communication is impeded by the inhibition of telephone frequencies due to passive security issues, and/or the presence of authorities [27]. Hence, an electronic communication system through mesh OppNets is presented here as a commercial and professional communications alternative in the field of broadcasting, in particular for mass events such as those described above.

This study aimed to examine a collaborative mesh network without a mobile data plan, Wi-Fi, or satellite devices in different contexts: in one-to-one communications, in group communications, and in a professional communication workflow. As such, an experiment was designed and carried out in which the subjects pretended to be professional journalists from a communications company that were required to cover a cultural event in a coordinated manner, communicating and coordinating their activity through this opportunistic network model. To our knowledge, no previous experimental study has used a mesh network for professional journalism as we have done here.

3. Materials and Methods

This study was part of a collaborative journalism experiment for event coverage, carried out in three days in the town of Almagro (Ciudad Real, Spain) during the International Festival of Classical Theater. Almagro is a small town in central Spain (Castilla La Mancha) with a population of around 9000 residents and it is a candidate to become a World Heritage Site, having been already declared a Historical–Artistic Zone. Its urban structure and the abundance of old stone buildings are a challenge for radio transmissions. The experiment performed was led by the Spanish Public Radio and Television (RTVE), with the participation of the Autonomous University of Barcelona (UAB), and by the University of Castilla La Mancha (UCLM), within the framework of the Chair of the Observatory for Innovation in News of the Digital Society (OI2) of the UAB-RTVE.

3.1. Participants

This experiment was conducted with 14 participants. The low number of participants was due to the lack of mesh communication devices available for this study. The participants (n = 14) were students (11) at the UAB and at the UCLM and audiovisual professionals from RTVE (3). There were seven women and seven men. Of the 11 students, there were 3 students of Audiovisual Communication studies, 3 were second-year Journalism students and the remaining 5 studied History, Teaching, Psychology or Sociology. The eight UAB participants received a 6 h course (at the RTVE Institute in Barcelona), which included a workshop on mobile journalism techniques, metadata protocols and configuration practices, and on video uploading to dedicated servers to broadcast audiovisual material from mobile devices. The three UCLM students received a similar course at their own university, coordinating the content and protocols. The three RTVE professionals who participated in the study were two RTVE journalists and the technological innovation manager at the RTVE Institute, the coordinator of this study and one of its authors. In all cases, informed consent was requested for participation in the experiment.

3.2. Mesh Communication Devices

In this experiment, 8 goTenna Mesh (GT01 to GT08) communication terminals (https://gotenna.com, accessed on 6 April 2023) were used, 6 of which were distributed to pairs of participants. The seventh device was carried by the coordinator and device number 8 was carried by one of RTVE's professional journalists, a controller of the communication flow and an external participant. The goTenna Mesh terminal used measures 12.7 × 3.8 × 1.27 cm, and it is basically a radio receiver and transmitter that emits on UHF frequencies in Europe, between 869,425–869,625 MHz (as opposed to 902–928 MHz in the US). This band, with 25 kHz channel widths, is dedicated to low-power applications and data in general, mobile, and broadcasting, according to the Radio Regulations of the International Telecommunication Union [28]. The terminal uses the mobile phone, to which it is paired by Bluetooth (versions 5.0 and 4.0+), as a screen interface for its dedicated app, and to receive and send conversations, locations, and information.

The terminal was initially developed by Jorge Perdomo following the loss of communication networks on the east coast of the United States after Hurricane Sandy in October 2012. He founded goTenna Inc. (Brooklyn, NY, USA) in November of that same year with his sister Daniela Perdomo and after successive improvements [29,30], they marketed the goTenna Mesh emitter and receiver device that connects via Bluetooth to a mobile phone that it uses as a screen. This device uses a dedicated app on the phone to send and consult text and locations, without the need for a central network, telephone towers, or Wi-Fi networks. All similar devices within a given range reinforce the decentralized network and they enhance the extension of the mesh network formed in this way. In 2019, the venture capital company Founders Fund considered that mesh communication systems were in an initial phase of market penetration and that other companies, such as Harris Corp. or Motorola, had neglected these developments. They provided $24 million to goTenna Inc. to diversify its growth into military areas, the public sector, and the consumer market [31,32]. In addition, the 2019 World Economic Forum selected goTenna as one of the world's 56 most innovative startup tech companies [33].

Note that goTenna is a commercial company and there are other tools and projects that could be good alternatives to the one used here (such as https://briarproject.org/, accessed on 6 April 2023 or http://laboratoirehubertcurien.fr/c3po-anr/index.html, accessed on 6 April 2023).

3.3. Mobile Devices

The participants were asked to use their own telephones linked to the OppNet terminals in mesh throughout the experiment, both for mesh communications, as well as for image capture and editing. The goTenna app is compatible with both Android and iOS terminals, and 7 terminals used here had an Android operating system (OS) and 7 had Apple's iOS system. Although the variation in the terminals did not affect the test with goTenna communicators, it produced differences in editing and in the quality of the images captured during the experiment, depending on the terminal's camera. As explained, a workshop was previously held to verify that all terminals had the app installed and correctly configured, without using their phone numbers but rather a generated identity (GID, a randomly generated 14-digit number starting with a 9, e.g., 9502 0359 4079 49), anonymously generated by the goTenna device by linking it via Bluetooth to the corresponding mobile terminal.

3.4. Range of the Devices

Before the experiment, the range and performance of the OppNet devices in the mesh were tested in real conditions to compare them with the manufacturer's proposed nominal range of 6.4 km (Km) from device to device with a single effective node. That nominal distance assumes that one of the devices is in high, clear terrain. To achieve this, two goTenna devices were given to professional journalists who, previously in another location, covered acts of an electoral campaign. The interpersonal communications were satisfactory at the meetings and at the venues where the electoral acts were held, where there were high concentrations of people. However, during testing the coverage did not exceed 3.5 km. The connection is very sensitive to obstacles, decreasing to 300 m inside some installations or buildings. In the context in which this study was carried out, it was considered that working with a distance of 1 km between the terminals would be sufficiently reliable and stable to locate the teams and maintain conversations.

3.5. The Experimental Session

On the afternoon of day 1, the 14 participants were gathered at a previously indicated meeting point in the Plaza Mayor, in front of the Town Hall in Almagro (Spain). They were about to tackle the challenge of creating professional video journalism with their mobile devices (as in mobile journalism or mojo) while everyone was in touch with the mesh OppNet. There they were told what the activity consisted of, any doubts were resolved, and the electronic mesh communication devices were given to them and linked to their mobile phones. The communication flow was then tested and the participants were given the following indications: (1) that they should make informative audiovisual works that can be distributed through any of the RTVE channels and upload it to a specific, designated folder housed in the cloud; (2) that they should send their location whenever requested by the coordinator; and (3) that they must regularly communicate with each other through the chat app of the device used. After performing the relevant technical tests, the session began. Specifically, the data from the definitive test of electronic opportunistic network communication were performed between 18:00 and 20:45 in the evening.

3.6. Analysis

In order to evaluate the data obtained in the experiment, different complementary approaches were adopted: a survey, a focus group, an analysis of the communication flow between the participants and of the video uploads to the RTVE platform, and their distribution. All the screens, with the locations and chats in the goTenna app, were also recorded.

3.6.1. Survey

We conducted a written survey of all the participants in the 10 days after the experiment using the Google Forms platform. The survey included both closed and open questions. In addition to the basic data provided by the respondent (personal data, participant number and telephone model used), the survey involved questions grouped into thematic areas: one-to-one communication, group communication, and the use of the integrated GPS location in the created communication flow of the Mesh OppNet.

3.6.2. Focus Group

At the end of the experimental session, an informal focus group was held with all the participants in order to obtain their personal opinions and impressions of the experiment. One of the authors moderated the session and was in charge of guiding the group's conversation, paying special attention to the topic of the study, and collaborative communication through mesh OppNets in a professional audiovisual environment. The session lasted 2 h.

3.6.3. Communication Flow among Participants

One of the main aims of this study was to assess the communication flow among the participants in the context described. As such, the participants were asked to hold all conversations in the context of this experiment in a common group within the goTenna app. Hence the group-interest and one-to-one conversations were visible to the coordinator of the experiment and could be readily monitored. An ONODO analysis [34] and a radial bar-chart representation [35] were used to evaluate the traffic and communication flow among the participants.

3.6.4. Video Uploads Made by Participants

The participants' videos and news uploads to the intelligent folder in the digital services cloud created by RTVE were made using a "Stream File Transfer Protocol" (SFTP). The videos were automatically transferred as "assets" (video clips) to the Video Stream Networks (VSN) cloud server for transcoding to a standardized video format for broadcasting, and with automatic detection of entities using artificial intelligence (AI) for analysis and metadata extraction. This allowed the material to be indexed for both editing or broadcasting, and for the registration of documentary collections.

4. Results

4.1. Survey

Of the 14 participants, 11 answered the survey (n = 11), of whom 6 were users of iPhones (6s, 7, 7 plus and SE), 2 used Honor phones (6x and 10), one a Huawei terminal, another a Samsung phone, and the last was a Nokia user. In total, six participants used an iOS system (Apple Inc., Los Altos, CA, USA) and five used Android (Google LLC, Mountain View, CA, USA). Correct device registration helps to cross the data in the communication research protocols [36]. In this case, the ratio seemed appropriate to test and experiment with a mesh network involving various mobile devices and OSs.

4.1.1. One-to-One Communication

If this tool had not been used to carry out individual communications in the context of the proposed experiment, participants indicated that they would have used: WhatsApp (eight participants), Signal (five), Telegram (two) and iMessage (one). Note that some participants proposed more than one instant messaging alternative. In this same context of one-to-one communication, the participants highlighted the following benefits of the system used here compared to the alternative systems: not having to pay for commercial data networks (seven participants), and no need for telephone coverage in order to communicate anywhere (four participants). In addition, the following drawbacks were mentioned: the limitations compared to data network systems as it is impossible to share photos and videos as goTenna devices linked to the mobile still only transmit text and locations; the need to have an additional device as well as the mobile phone, the respective cost; and the initial complexity in configuring the device for an amateur user.

4.1.2. Group Communication

When covering informational and/or audiovisual events in a professional sphere, it is of interest to establish a group communication channel among all the team members involved. In this context, participants considered that, if they had not used the protocol described here they would have used: WhatsApp (seven participants), Signal (four), Telegram (one), SMS (one) and iMessage (one). Again, some participants proposed various alternatives. In this context, the following benefits of the goTenna network were highlighted: the location of all the team members on the map; the use of the ‘shout’ option to communicate with any user other than their own contacts; and the independence from mobile data networks or coverage, thereby guaranteeing a connection in crowded environments. The fact that it is a free system that does require payment to use the network was also mentioned. Among the disadvantages for this type of group communication were the initial complexity of configuration; the fact that audiovisual elements other than texts cannot be sent (audios, videos, photographs); the need to purchase an extra device; and the fact that the system does not track the user, who has to constantly report changes in location within the app. This is very interesting, because goTenna does facilitate localization if the user gives permission. However, what happened here is that the coordinator (GT7) frequently requested the observers to give their location in order to explicitly test the system. In opportunistic mesh networks the sending of a location can be ignored for privacy, and it is not necessary to identify the intermediate nodes since they are terminals that simply act as repeaters in the network, helping to extend the signal. Indeed, the privacy of a decentralized network is one of its most interesting features.

4.1.3. Use of Localization Tools Integrated into the Communication Flow

The devices integrate pins and location points into the chat communications as GPS location tools. These tools were considered to be effective for the coordinator to indicate where a broadcaster should be and what information should be covered by 90.1% of the participants (10 out of 11). During the experiment, all the participants considered that the indications were sufficiently clear and practically all of them (90.1%) considered that using this system facilitated the coordinator’s work in a professional environment in which information must be covered by several informants. Only one participant (9.1%) considered the device difficult to use and ineffective in locating the coordinator so that he could manage the team. Conversely, practically all the participants (90.9%) considered it easy to use and useful. None considered that this location system was invasive at an event of this type. The use of a pin to establish a meeting point to situate all members of the team at a given moment was considered useful by all the participants. As alternatives to the tool used here, they proposed: WhatsApp (four participants), Google Maps (two) and walkie-talkies (one).

4.2. Focus Group

During the informed discussion held just after the session ended, participants focused on issues in two areas: the technical questions of use and immediacy; and the ethical or professional issues. Regarding communications through an opportunistic network, the general opinion was surprise at not knowing about these devices, which can be used free of charge. There was general agreement on their great practical utility in the coordination of event coverage. Among the problems, the initial complicated configuration of the devices was highlighted, as well as the problems in sending images, in sharp contrast to other chat like Apps usually used on phones. Professional journalists were of the opinion that they would use it without hesitation for sports coverage in stadiums, outdoor sports events or urban demonstrations at which a team of reporters is required. Its usefulness to coordinate live programs in noisy environments was also highlighted.

In terms of the ethical issues, the participants noted a lack of supervision and control with these devices, which could permit illegal use, and they lamented that a similar communications system was not implemented by default in mobile phones in the mountains, for example. It was concluded that mobile phone operators would not be interested in a system that is independent of data plans and the possibility of billing.

It should be noted that the day after this experimental session, video recordings continued and one of the participants' movements coincided with the visit of the Queen of Spain to the Almagro International Festival of Classical Theater. As expected, this produced an intermittent failure of all telephone systems due to the customary use of frequency inhibitors in these circumstances (see Figure 3). The group covering this information indicated that the OppNet device continued to work normally, and the mesh communications remained intact. Although this event did not occur in the experimental session, we believe it is relevant and worthy of mention.

Figure 3. Mobile phone with an OppNet device working next to the official car of the Queen of Spain. Note. Source: Photo courtesy of David Corral, RTVE.

4.3. Communication Flow among Participants

Participants carried out both one-to-one communication (between specific individuals) and group communication (with the entire group). The communication flow among the participants was carried out in the same common space, a chat within the goTenna app created ad hoc by the coordinator of this project to transparently record the entire communication flow in this experiment. In total, 90 communication exchanges between all the participants (64 text communications, 24 locations and 2 pins) were made over two hours and forty-five minutes (Table 1). Note that no message failed in the emissions.

Table 1. Dynamics of the communication flow.

Time	Type	GT Sender	GT Receiver
6:42	Text	1	Everyone
6:43	Text	7	Everyone
6:43	Text	4	Everyone
6:43	Text	1	Everyone

Table 1. *Cont.*

Time	Type	GT Sender	GT Receiver
6:43	Text	4	Everyone
6:43	Text	3	Everyone
6:43	Text	5	Everyone
6:44	Text	6	Everyone
6:44	Text	2	Everyone
7:06	Text	7	Everyone
7:07	Location	7	Everyone
7:07	Text	7	Everyone
7:07	Text	3	7
7:08	Text	7	3
7:08	Location	3	7
7:09	Text	7	3
7:09	Text	3	7
7:09	Text	3	7
7:09	Text	7	3
7:09	Location	7	Everyone
7:10	Text	7	Everyone
7:12	Location	2	Everyone
7:17	Text	7	Everyone
7:17	Text	7	Everyone
7:18	Text	7	Everyone
7:19	Text	4	7
7:19	Text	7	4
7:19	Location	7	4
7:19	Text	4	7
7:19	Text	7	4
7:21	Text	2	7
7:21	Text	3	7
7:21	Text	7	Everyone
7:22	Location	3	7
7:23	Location	7	Everyone
7:23	Text	1	7
7:23	Location	1	7
7:24	Text	7	1
7:25	Text	7	2, 4 and 8
7:25	Location	2	7
7:25	Text	7	2
7:26	Text	4	7
7:26	Text	7	Everyone
7:29	Location	4	7
7:30	Text	7	4

Table 1. *Cont.*

Time	Type	GT Sender	GT Receiver
7:30	Location	7	Everyone
7:30	Text	7	6 and 8
7:31	Text	6	7
7:32	Text	7	6
7:32	Location	6	7
7:32	Location	7	Everyone
7:32	Text	4	7
7:32	Location	4	7
7:33	Text	7	4
7:40	Text	3	7
7:40	Location	3	7
7:41	Text	7	Everyone
7:42	Location	2	7
7:43	Location	2	7
7:46	Text	1	7
7:46	Location	1	7
7:51	Text	6	7
7:51	Location	6	7
7:52	Text	7	6
7:52	Location	7	Everyone
7:52	Text	7	4
7:52	Text	7	2
7:52	Text	7	1
7:53	Text	7	6
7:53	Text	7	5
7:53	Text	7	8
7:54	Text	7	Everyone
7:53	Location	6	7
7:55	Text	7	6
7:56	Location	3	7
7:57	Text	7	Everyone
7:58	Text	7	Everyone
7:59	Text	7	3
8:00	Text	7	Everyone
8:00	Location	7	Everyone
8:01	Text	4	7
8:01	Text	4	7
8:02	Text	7	4
8:09	Text	7	Everyone
8:11	Pins	7	Everyone
8:14	Text	7	Everyone

Table 1. *Cont.*

Time	Type	GT Sender	GT Receiver
8:14	Location	7	Everyone
8:20	Text	3	7
8:21	Text	7	3

4.3.1. Communications, Locations and Pins

The results regarding the communications, locations and pins maintained through the eight goTenna (GT) devices used are presented below. Communications involved text messages in the common chat, which involved the communication of information among the users. Locations were shared by each participant by indicating their GPS coordinates, coordinates that were automatically placed on an internal map in the mobile app. These locations enable the members of the team to indicate where they are to the rest of the team and/or the coordinator. When the map is accessed, the location of a user and the device's own location appears, making it possible to see how far you are from a specific participant. Finally, pins are fixed so that a user can establish stable locations of interest that can be placed on the map (other than their own coordinates), e.g., meeting points, points with Wi-Fi connections, points to go to cover information, etc.

The weight of the different communication modalities (text, location, and pins) among all the terminals (GT01 to GT08) was represented (Figures 4 and 5). 60.9% of text communications were carried out by a single terminal (terminal GT07), one of the authors of this study. This participant was the coordinator of the pilot session and therefore, he was responsible for the communications in general. This user was in charge of giving instructions to the rest of the participants, requesting locations or pins, and coordinating their participation. From the communications of the rest of the users, it was notable that different users communicated distinctly. For example, while terminal GT04 made 12.5% of the communications, terminal GT05 barely made 1.6% of them. Moreover, terminal GT08 did not participate in the communication flow, as this was a professional from RTVE who was monitoring the session externally and who decided not to actively participate by sending text communications to the rest of the group. Regarding the locations, we see that a total of 25 were established during the experiment and again, the coordinator (GT07) was the most active user with 9 of these (36%). The rest of the participants also sent their location during the experiment, except for GT05 who, as seen previously, did not participate significantly and did not share the location at any time. Finally, with regard to the pins, these were established on two occasions, in both instances the pins were placed on the map by the coordinator (GT07) to indicate the start point and the arrival point during the experiment.

4.3.2. Connections, Relevance and Nuclearity (K-Index)

The connections refer to the number of relationships for each node (Figure 6), and the relevance of each node is calculated on the basis of the number of connections and the relevance of the nodes it is connected to (derived from their number of connections). The nuclearity or k-index measures in which layer of the network a node is and the number of links in a complete mesh responds to the formula $N = n\,(n - 1)/2$. The k-index indicates the layer of the network a node belongs to. The layer with the highest k-index is the core of the network. Layer k includes those nodes with at least k connections to other nodes in the same layer [34,37]. In our case, there were 28 possible bidirectional links with 8 terminals. The core of the network was the layer with the highest k-index and the k layer was made up of nodes with at least k connections among them. When these parameters were represented (Figure 5), a total of 562 connections were made (GT01 made 51 connections; GT02, 49; GT03, 54; GT04, 60; GT5, 40; GT06, 44; GT07, 228; and GT08, 36). The most relevance was attributed to GT07 (1.00), after which two groups were detected: one with a relevance between 0.40 and 0.51 (GT01 obtained a relevance of 0.42; GT02, 0.40; GT03, 0.49; and GT04, 0.51); and the other with a relevance below 0.40 (GT05 obtained a relevance from 0.34; GT06, 0.38; and GT08, 0.32). Regarding nuclearity, we identified a first group with a k-index of 44, consisting of GT03, GT04 and GT07, and a second group with a k-index of 41, consisting of GT01, GT02 and GT6. In addition, GT05 had a k-index of 39 and GT08 a k-index of 36. Nuclearity shows differences in the use of the system among participants, and it can be illustrative for future strategies in similar experiments or professional situations.

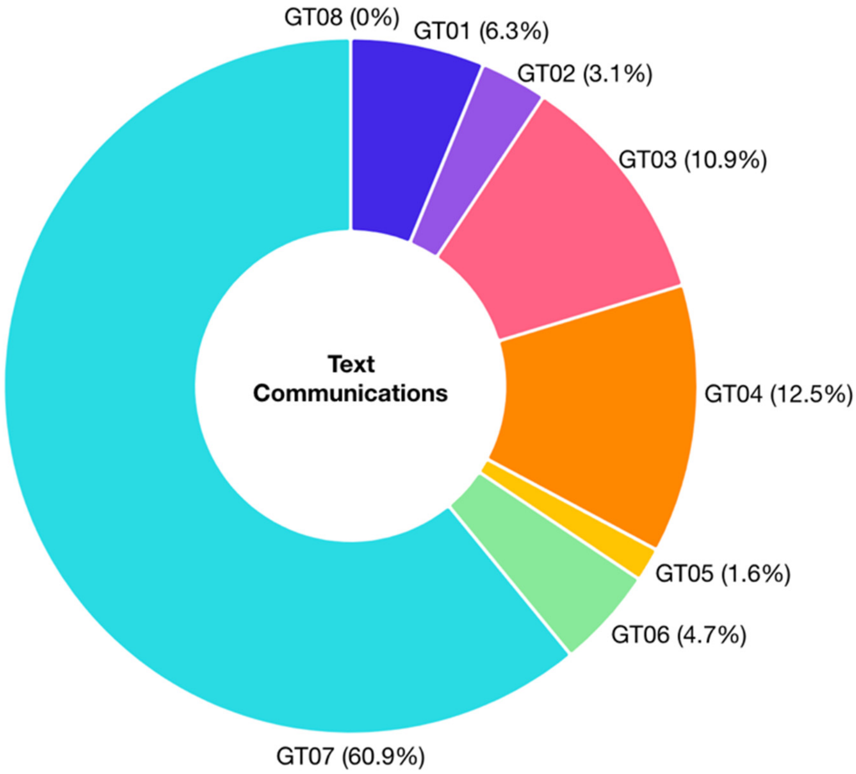

Figure 4. Pie chart with the text communication flow done by participants.

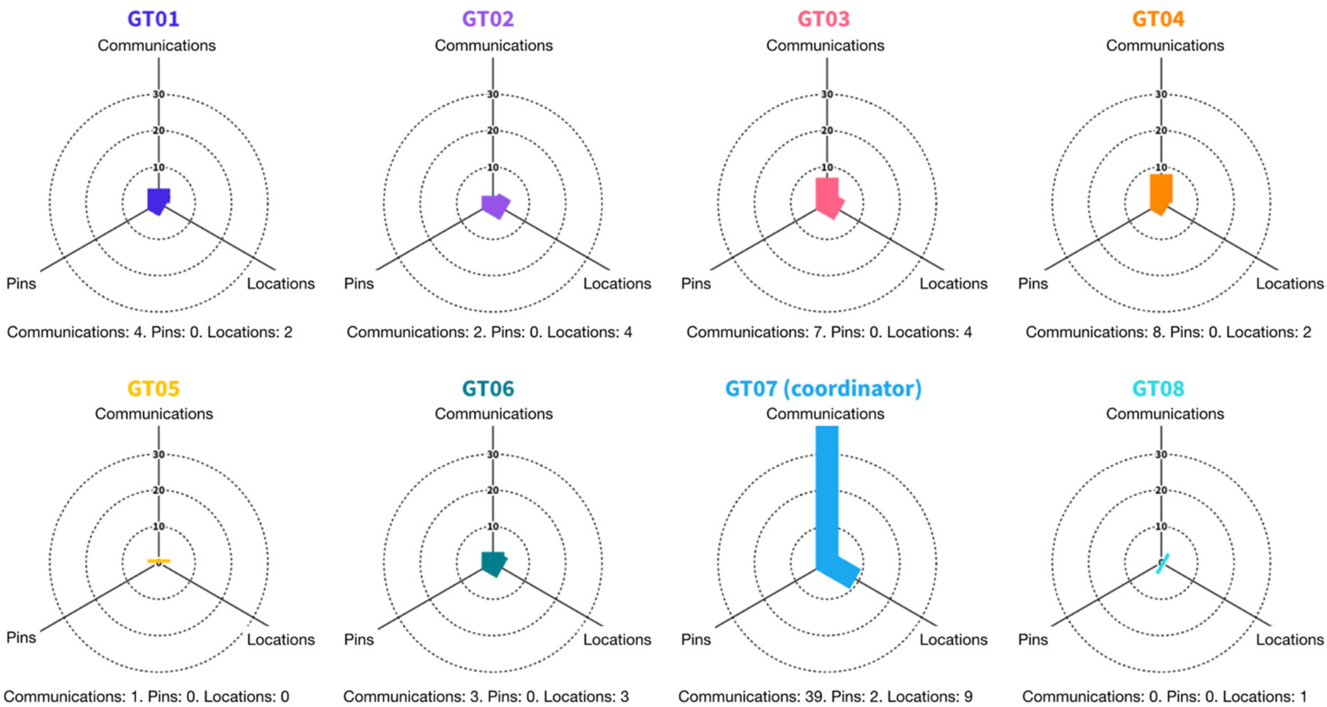

Figure 5. Radial bar chart of the communications, pins, and locations.

	Connections	Relevance	Nuclearity
GT01	51	0.42	41
GT02	49	0.40	41
GT03	54	0.49	44
GT04	60	0.51	44
GT05	40	0.34	39
GT06	44	0.38	41
GT07	228	1.00	44
GT08	36	0.32	36

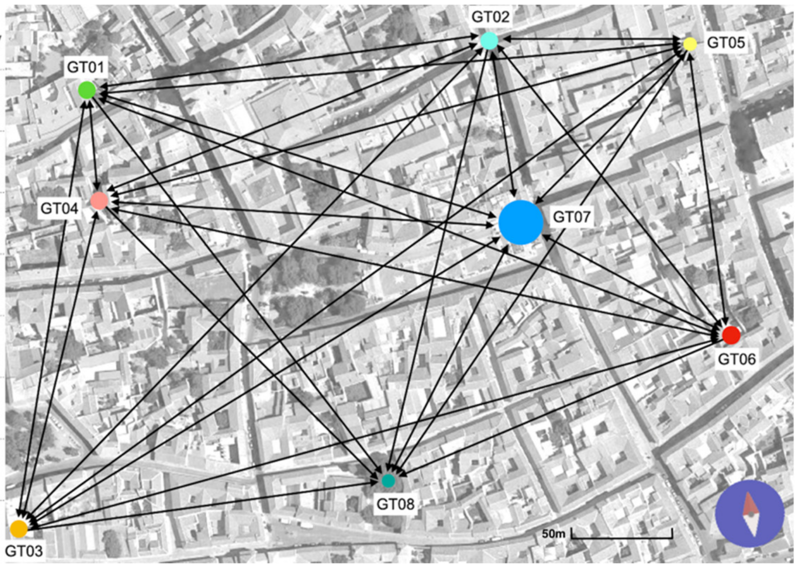

Figure 6. Map of the flow (connections, relevance and nuclearity) and the approximate situation of the participants at 8:15 p.m.

4.4. Videos Uploaded by the Participants

During the session, and in the time slot from 6:00 p.m. to 9:00 p.m., a total of 46 informative audiovisual pieces were uploaded to the VSN Explorer cloud platform by the 14 participants. Thus, while the subjects were carrying out the one-to-one and group communications and establishing the location and the meeting-point pins, they were also generating audiovisual pieces. This was important to analyze the communication as though it was potentially being used in the context of professional broadcasting. For the participants who did not upload audiovisual pieces to the network, the analysis of the communication protocol lost some value because these subjects will only have focused on communication itself, whereas one goal was to study communication in the context of the creation of audiovisual content.

5. Discussion

Several reasons have been put forward to explain why mesh OppNets are not deployed extensively. It is true that the companies developing these systems do not have a clear implementation policy, the battery consumption reduces the autonomy of the devices and above all, a free communication infrastructure represents a clear threat to the monopoly of telephone operators [38]. The results regarding the communications and coordination of professional teams were indeed useful, once the devices were configured and linked to the mobile phones through the dedicated app.

5.1. Mesh OppNets in One-to-One Communication

The biggest benefit of mesh OppNets is the fact that it does not use commercial data networks and there is no need for telephone coverage in order to communicate to anyone. This type of collaborative mesh communication without a mobile data plan, Wi-Fi or satellite can revolutionize one-to-one communication in local areas. However, the fact that the mobile app was unable to share photos and videos in electronic one-to-one communication flow is one of the most important limitations in the actual context, with dozens of options to do so. Note that some of the weaknesses raised here about the communication flow are not related to the design of an app, but to the frequency band used by the system. Improvements in this technology may be able to solve this issue, however it does not seem to be an option now.

5.2. Mesh OppNets in Group Communications

According to our results, there is no specific problems or limitations with using mesh OppNets in group communications. It seems a good alternative for sending texts to current options. A benefit on this regard is the easy way to get the location of the rest of participants. This seems of special interest when users are in the same area or region and they want to know where the members of the group are located.

5.3. Mesh OppNets in Professional Communication Workflows

We aimed to test the coverage and effectiveness of a mesh OppNet network to coordinate communications while producing an audiovisual news piece by journalists. With the obtained results in this experiment, we can conclude that mesh OppNets can be implemented for intercommunication processes in the context of professional journalism. These networks do not impede the creation of informative audiovisual content, yet they offer the benefit of network communication when the connection through mobile devices (telephone and Internet) is compromised by saturation, emergency circumstances or the use of inhibitors. In contexts where the use of telephone data is limited, this type of electronic communication can aid professionals who must save their data for the transmission to the cloud (i.e.,: a newsroom and/or social networks). It is a mode of communication that while having many advantages in terms of data saving, and in location and connection integration, regardless of the technical context, it also has some drawbacks that must be borne in mind. Among these, the limited spatial coverage stands out, which might limit the use of mesh OppNets in professional contexts to those events in which all members involved in the communication flow are within a given communication radius. There are currently places like New York where this type of communication can be implemented without considering this drawback, given that their use is more widespread and there are hundreds if not thousands of nodes that increase the spatial coverage of the mesh network. However, in other areas there may be hardly any nodes to amplify the coverage of a single device. That is why intragroup communication at mass events is today considered to be the ideal working context for the use of these mesh networks, particularly in the field of professional journalism. However, a limitation of this work is the lack of use of a system that tracked participants locations at all the times. In a professional context as the one described here, it would be useful to have access to the movement of the users and to analyze the impact of mobility on communications.

5.4. Mesh OppNets as an Emergent Technology in Future Smart City

In the future, it is likely that devices will be available that facilitate mesh communication without the need for a phone terminal. Moreover, further research should assess the value of mesh OppNets in smart cities in the advent of this post-pandemic society, where internal electronic communication flows will have to adapt more quickly to a new way of consuming geolocated content more locally and on a daily basis. In this context, Wi-Fi direct-based protocols should be taken into account, and further research should be done to determine if their limitations (such as scalability or routing) [39] could make this technology suitable for practical mesh networks such as the one described here.

The increased spread of mesh OppNets is a phenomenon that will become important in areas with poor mobile coverage, in states of emergency, and in military use. Indeed, they are already becoming evident in urban settings and for informal conversations. As such, communication studies and smart city designers must pay attention to community implantation experiments and it will be necessary in subsequent studies to understand their use in informal networks within cities, paying attention to the content that early adopters of this technology implement in these communications. Electronic commerce research must be alert to this new method of electronic communication.

Author Contributions: Conceptualization, M.Á.M.-P. and C.A.-S.; methodology, M.Á.M.-P. and C.A.-S.; software, M.Á.M.-P. and C.A.-S.; validation, M.Á.M.-P. and C.A.-S.; formal analysis, M.Á.M.-P. and C.A.-S.; investigation, M.Á.M.-P. and C.A.-S.; resources, M.Á.M.-P.; data curation, M.Á.M.-P.; writing—original draft preparation, M.Á.M.-P. and C.A.-S.; writing—review and editing, M.Á.M.-P. and C.A.-S.; visualization, M.Á.M.-P. and C.A.-S.; supervision, M.Á.M.-P.; project administration, M.Á.M.-P.; funding acquisition, M.Á.M.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Department of Technological Innovation of Institute RTVE (Spanish Public Television, RTVE), the Almagro Classical Theater Festival and Observatory for Innovation in News for the Digital Society (OI2).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We acknowledge the logistic assistance of the City Council and the Almagro Classical Theater Festival, and the participation of students from the Autonomous University of Barcelona (UAB) and the University of Castilla La Mancha (UCLM), within the framework of the Chair of the Observatory for Innovation in News from the Digital Society (OI2) of the UAB and RTVE. We thank Toni Vilalta, Aitor Falcó and Roberto Pascual from Video Stream Networks (VSN), and Sonia Morales, Carmen Pérez, Virginia Bazán, David Corral, Pablo Beceiro, and Carlos de la Morena from RTVE. We thank Mark Sefton for his support with the English language editing.

Conflicts of Interest: The authors declare no conflict of interest.

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