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Hybrid Routing Algorithm for Emergency and Rural Wireless Networks

R. A. Santos, A. González-Potes, M. A. García-Ruíz, A. Edwards-Block
Faculty of Telematics, University of Colima,
Av. Universidad # 333, C. P 28400, Colima, Col., México, phone: +52 312 3161165; e-mail: aquinor@ucol.mx, apogon@ucol.mx, mgarcia@ucol.mx, arted@ucol.mx
V. Rangel-Licea
Department of Telecommunications, National Autonomous University of México,
C. P. 04510, México, D. F., phone: +52 312 3161165; e-mail: victorr@fi-b.unam.mx
L. A. Villaseñor-González
CICESE Research Centre,
Carr. Tijuana-Ensenad, km 113. C. P. 22860; phone: +52 312 3161165; e-mail: luisvi@cicese.mx

Introduction

The use of wireless networks for emergency and rural communities has received increased attention from both research and industry. When traditional communication and electrical infrastructure fails because of earthquakes, natural disasters or other unforeseen causes, a temporary and reliable back-up system must provide sufficient energy to power an ad-hoc low-power communications grid.

The opportune and accurate broadcast of information during disasters is vital component of any disaster response program designed to save lives and coordinate relief agencies. In moments of disaster when conventional systems are down, wireless broadband networks can provide access to databases that provide audio, video or geographical information essential to provide emergency assistance.

Emergency and rural wireless networks need to include fault tolerance (robustness), provide low cost voice/video communication, and possess different architectures that are easy to set up (e.g. ad-hoc mode). Furthermore, they should also be flexible in order to provide interoperability among different wireless technologies, including existing and operational systems, plug-and-play functionalities, and proactive and reactive algorithms.

The main reasons behind the success of HWMN technology are the following: 1) very inexpensive network infrastructure due to the proliferation of IEEE 802.11 based devices, 2) easiness of deploying and reconfiguring the network, 3) broadband data support, and 4) the use of unlicensed spectrum [1]. Due to these advantages, HWMN find many applications in a variety of situations ranging from fixed residential broadband networking based on rooftop wireless mesh networks to emergency response networks for handling large scale disasters.

This work analyzes the feasibility of VoIP in a HWMN for emergency and rural communications over the PANDORA protocol. This architecture possesses two distinct layers:

(1) an ad hoc network which is composed of Wireless Mesh Clients (WMC) and (2) Wireless Mesh Routers (WMRs) with a backbone connection between the WMRs. The two types of nodes of a Wireless Mesh Network (WMN) suffer different constraints. WMCs located at the end points have limited power resources and may be mobile, while WMRs possess minimum mobility and do not suffer from power constraints.

VoIP applications must take Quality of Service parameters such as bandwidth, jitter, latency, and packet loss into account. We test these parameters over the PANDORA protocol using the PRIO, HTB, and DSMARK queuing disciplines and four kinds of traffic, including TCP, voice, video and UDP.

The remainder of this paper is organized as follows: Section 2 reviews state of the art literature related to routing algorithms for wireless mesh networks. Section 3 describes some of wireless mesh network testbeds. Section 4 explains the PANDORA protocol for emergency and rural wireless networks. Section 5 describes the scenarios simulated and results obtained. Finally, Section 6 summarizes our work and proposes future research.

State of the art of routing algorithms for wireless mesh networks

A wireless network for emergency and rural communities can be easy deployed using wireless mesh technology. Several wireless mesh routing protocols have been reported in the literature [2 - 5]. Authors in [2], describe the Mobile Mesh Routing Protocol (MMRP), which is a robust, scalable, and efficient mobile ad hoc routing protocol based on the "link state" approach. A node periodically broadcasts its own Link State Packet (LSP) on each interface participating in the protocol. LSP´s are relayed by nodes, thus allowing each node to have full topology information for the entire ad hoc network.

In [3], the authors proposed the Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) protocol, which is a proactive, link-state routing protocol designed for mobile ad hoc networks. TBRPF provides hop-by-hop routing along the shortest paths to each destination. Each node running TBRPF computes a source tree based on partial topology information stored in its topology table, using a modification of Dijkstra´s algorithm. To minimize overhead, each node reports only part of its source tree to neighbors. TBRPF uses a combination of periodic and differential updates to keep all neighbors informed of the reported part of its source tree.

In [4] AOMDV, a well known ad hoc routing algorithm and variant of AODV, is described. AOMDV provides loop-free and disjoint alternate paths. During route discovery, the source node broadcasts a ROUTE_REQUEST packet that is flooded throughout the network. In contrast to AODV, each recipient node creates multiple reverse routes while processing the ROUTE_REQUEST packets that are received from multiple neighbors. Dynamic Source Routing (DSR-MP) is also described in [3]. In the multi-path version of the DSR protocol, each ROUTE_REQUEST packet received by the destination is responded to with an independent ROUTE_REPLY packet.

Authors in [5], present the An-hoc On-demand Distance Vector Hybrid Mesh (AODV-HM) Protocol. The aim of AODV-HM is to maximize the involvement of mesh routers into the routing process without significantly lengthening the paths. In addition, the authors want to maximize channel diversity in the selected path. To implement these features, they make two changes to the RREQ header. First, they add a 4-bit counter (MR-Count) to indicate the number of mesh routers encountered on the path taken by the RREQ. They further add a 7-bit field (Rec-Chan) to advertise the optimal channel to be used for the Reverse Route.

Wireless Mesh Networks Testbeds

Recently, a number of testbeds have been deployed by the research community, moving the focus of research activities on real implementations. Nevertheless, only limited research has encompassed a global approach that tackles the two main tasks of a WMN: the self-organization of the mesh backbone and the seamless connectivity for end-users [6-10]. [6] describes a roofnet project which is an experimental 802.11b/g mesh network in development at the MIT Computer Science and Artificial Intelligence Laboratory. Currently consisting of a network with 20 active nodes, Roofnet provides broadband Internet Access to users in Cambridge. [7] shows the MobiMESH architecture that has been implemented in a real life testbed in the Advanced Network Technologies Lab at the Politecnico di Milano. The architecture is designed to seamlessly apply the complex standard 802.11 to its nodes. Seamless mobility is the primary issue, since WLAN clients roam within the coverage area of the mesh without losing connectivity. [8] describes a wireless mesh network developed at Carleton University. The wireless mesh network architecture consists of two parts: the mesh backbone and local footprints. All the mesh nodes are equipped with two wireless interfaces. One is an IEEE 802.11a/g compliant radio, which is the backbone traffic carrier. Another is an IEEE 802.11b radio, which provides access to wireless clients in the local footprint. [9] shows the wireless mesh network testbed, called MeshDVNet, which was developed in the LIP6 laboratory of Université Pierre et Marie Curie. This work is mainly concerned in an efficient cross-layer routing to increase as much as possible the transport capacity of the mesh backbone; and in a mechanism able to effectively manage users' mobility. Both tasks have been integrated in MeshDV, a unique framework that leverages on the two-tier arquitecture of WMNs. And in [10], authors describe the feasibility of deploying a community mesh network to share broadband Internet access in a rural neighborhood with stationary nodes.

The weakest point of the three routing protocols considered in this study is that they are measured in terms of the number of hops or the shortest path. However, these parameters are not always the most adequate when dealing with wireless mesh networks primarily because of the dynamic characteristics of their links. Another important concern is that the previously mentioned protocols are adaptations of protocols for wireless ad hoc networks, meaning that they were not specifically developed for wireless mesh networks. The PANDORA protocol we developed has been specifically developed for wireless mesh networks. Consequently, it considers factors such as energy, bandwidth, location and number of users within the specific context of wireless mesh networks.

PANDORA protocol

The PANDORA Protocol has been designed for Rural and Emergency Wireless Networks where no physical infrastructure exists. It was developed in C language under Linux platform, specifically UBUNTU using the 2.6.15 kernel. Figure 1 shows the structure of the PANDORA protocol. Two different nodes exist in level 1: IROOT and NBB. IROOT, the root node, also includes two interfaces, one which has a link to the INTERNET and another that is connected to the NBB nodes that form the backbone.

NROOTs, in level 2, are actually gateways between NBB nodes and LEAF nodes. Level 3, the final level of the PANDORA architecture, consists of LEAF nodes that have limited energy, processing and transmission resources. Finally, there is another node called UNDECIDED, which is the initial state of all network nodes before they become NBB, NROOT or LEAF nodes.

Routing protocol in PANDORA

The routing protocol presented in this paper aims to achieve two goals. First, it tries to make optimal use of high capacity mesh routers in a hybrid WMN by routing packets along paths consisting of mesh routers whenever possible. This not only increases the overall throughput and reduces latency; it also helps to conserve battery power of client devices. Secondly, we employ several metrics at two levels: bandwidth, energy, location, and number of users.

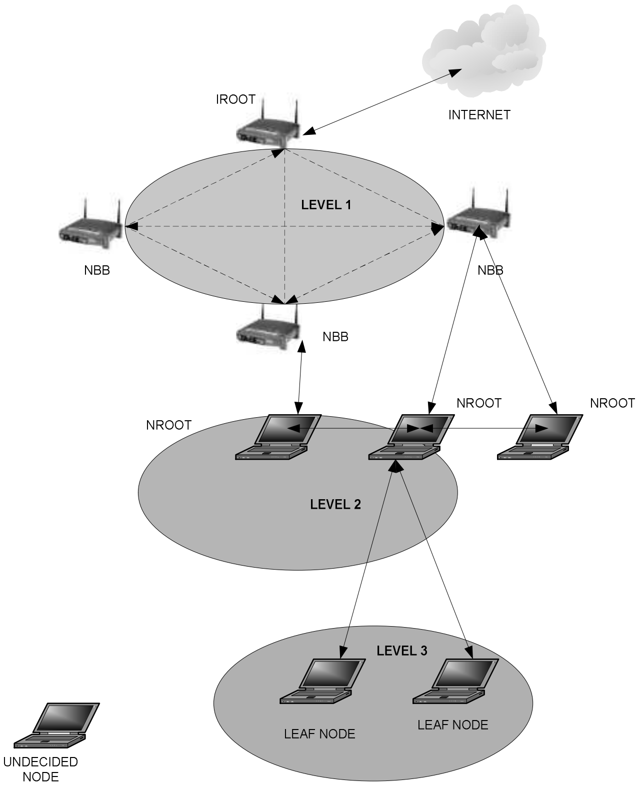


Fig. 1. PANDORA Protocol

Group formation at the level 1 (NBB node)

1. The IROOT node executes a script to obtain its IP and configuration parameters for its wireless interface, including the MAC address geographical location, and a time stamp, as well as information about the battery level and bandwidth.
2. Then the IROOT node changes its flag status to B, indicating that this is the root node with access to the Internet.
3. Next, the IROOT node clears the neighbor table and starts the routing function.
4. The undecided node then sends Hello packets asking to join the IROOT.
5. After this, the undecided node joins the IROOT and changes its state to a NBB node.
6. The NBB node then collects information from neighbor nodes and sends it to the IROOT, which adds the information to the main table.
7. Finally, the IROOT node forwards the main table to its neighboring NBB nodes. With this information, each NBB node compiles a complete view of the network.

Routing at the level 1

NBB nodes forward small packets every 5 seconds to indicate that they are "alive." If a NBB node needs to inform neighbor nodes of network changes, including nodes entering and exiting the network, they will send a larger packet containing the ID of the nodes, the updated network structure, node position, actual node energy, and bandwidth of the neighborhood, among others, which is retransmitted by neighboring nodes until the packet reaches the IROOT node.

Group formation at the level 2 (NROOT node)

Several conditions need to be met to convert an Undecided node to an NROOT node.

1. A NBB node verifies that its maximum number of NROOT nodes has not been reached.
2. The Undecided node executes three steps:
    a) First, is sends one Hello packet per second.
    b) If the Hello packets are listened to by the NBB node, the NBB node replies to the Undecided node.
    c) Finally, the Undecided node asks to be member of the NBB node and becomes an NROOT node.

Group formation at the level 3 (leaf node)

Several conditions need to be accomplished to convert an Undecided node to a Leaf Node.

1. A NROOT node verifies that its maximum number of Leaf nodes has not been reached.
2. The Undecided node then executes two steps:
    a) First, it sends one Hello packet per second.
    b) If the Hello packets are listened to by a NROOT node, the NROOT node replies to the Undecided node and the Undecided node asks to be a member of the NROOT node, thus becoming a Leaf node.

Routing at the level 2 within the same group

The NROOT node has the information of all of its Leaf nodes. Furthermore, each Leaf node also has the information of each neighbor Leaf node and its NROOT node. Thus, when a Leaf node source sends information to another Leaf node destination, it broadcasts the packet directly to the destination node.

Routing at the level 2 neighbor group

This is the case, when one Leaf node wants to communicate with another Leaf node, but they belong to different NROOT nodes. The procedure is the following: the Leaf node source searches in its routing tables. If it has the Leaf node destination, it sends the packet directly to the Leaf node destination. Otherwise, the Leaf node source sends the packet to its NBB root node throughout its NROOT node. The NBB node asks its NBB neighbor nodes if they have registered the Leaf node.

Testing the PANDORA protocol

PANDORA was developed and tested on a Linux system using UBUNTU with 2.6.15 and 2.6.17 kernels with and without QoS. More detailed information concerning the PANDORA protocol can be found in [11].

The PANORA protocol was evaluated according to the following parameters:

1. Available network bandwidth, which allows one to determine network capacity.
2. Traffic of real time data, which permits one to ascertain bandwidth, delay, jitter, and packet loss.
3. Traffic only data (TCP)
4. Traffic data + voice
5. Traffic data + voice + video
6. Traffic UDP without Marks

Queuing disciplines used in the PANDORA protocol

The PRIO, HTB, and DSMARK queuing disciplines were used to evaluate the Quality of Service provided by PANDORA. The PRIO qdisc is a classful queuing discipline that contains an arbitrary number of classes with different priorities. When a packet is enqueuingd a sub-qdisc is chosen based on a filter command that is given in tc [12]. HTB is a more understandable, intuitive and faster replacement for the Class Based Queuing (CBQ) qdisc in Linux. Both CBQ and HTB help control outbound bandwidth on a given link. Both use one physical link to simulate several slower links and to send different kinds of traffic on different simulated links. DSMARK is a queuing discipline that offers the capabilities needed in Differentiates Services (also called DiffServ, or simply, DS). DiffServ, along with Integrated Services, is one of two actual QoS architectures that is based on a value carried by packets in the DS field of the IP header.

Tools used in the evaluation of the PANDORA protocol

Two different tools were used to evaluate the PANDORA protocol: IPERF [13] and ECHOPING [14]. IPERF 2.0.2 is a traffic injector that reports bandwidth, jitter, packet lost, and traffic behavior for TCP and UDP. ECHOPING allows the measurements of the traffic delays of a network.

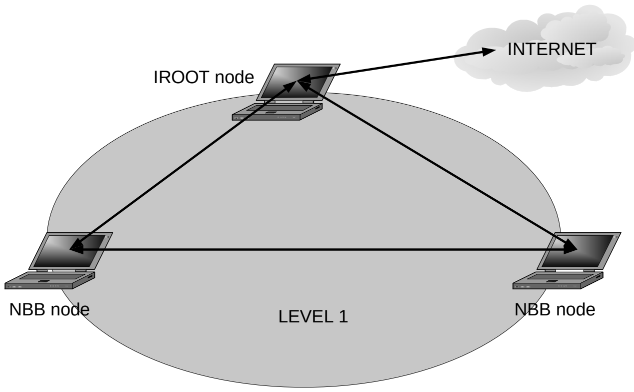
Testbeds utilized in the PANDORA protocol

Fig. 2 shows the two scenarios employed in the evaluation of the PANDORA protocol. In scenario 1, three laptops were used, with one of them configured as the IROOT node and the other two as NBB nodes; this is an example of a small emergency network. The scenario 2 is used to evaluate the PANDORA protocol considering three levels. This test bed included Level 1 and Level 2 elements with four laptops functioning as IROOT, NBB, NROOT and LEAF nodes, this is a classical example of a hierarchical network for a small community or rural network. Three sizes of packets were utilized to evaluate the performance of PANDORA, 64, 1024, 2024 bytes.

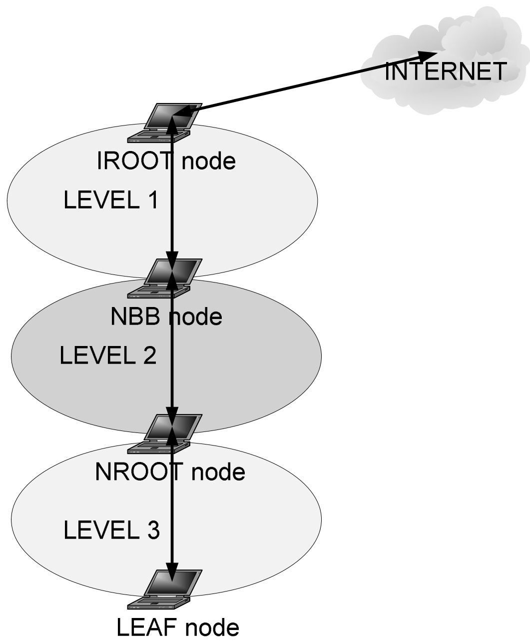
Analysis of results of the PANDORA protocol

Fig. 3 shows the bandwidth utilized by different traffic flows generated introduced into scenarios 1 and 2. Traffic is injected into the network without any queuing discipline. The TCP traffic flow starts at second 0, at the second 20 begins the audio, at second 40 originates the video and finally, at the second 60 starts the UDP traffic flow.

When packets of 64 bytes are injected to the network at a speed of 300 Kbps, they significantly affect network bandwidth in both scenarios. Packets of 1024 bytes did not significantly affect the network in scenario 1, but effective bandwidth was reduced in scenario 2. Finally, packets of 2024 bytes did not alter the performance of the network in either of the scenarios.



Scenario 1



Scenario 2

Fig. 2. Scenarios 1 and 2, used to evaluate the PANDORA protocol

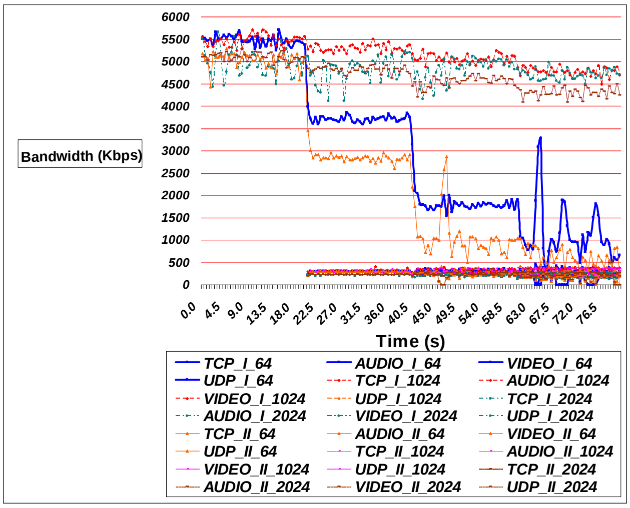


Fig. 3. Bandwidth used by different traffic flows without applying any queuing discipline using 64, 1024 and 2024-bytes packets

Fig. 4 shows the bandwidth utilized for the different traffic flows generated in scenarios 1 and 2 utilizing a PRIO qdisc. When 64 byte packets are injected into the network at 300 Kbps, they severely affect network bandwidth in both scenarios. However, network performance is not significantly affected with packet sizes of 1024 and 2024 Kbps.

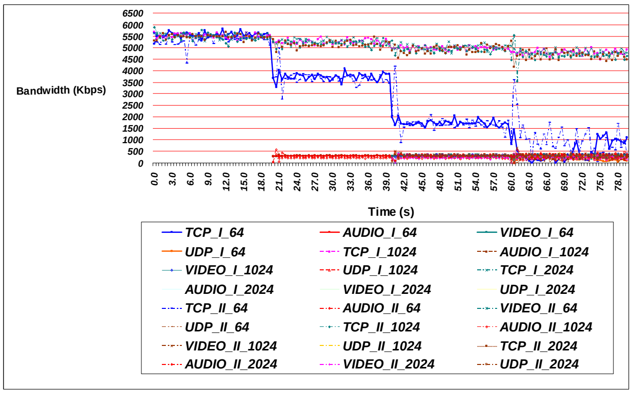


Fig. 4. Bandwidth used by different traffic flows with PRIO qdisc and 64, 1024 and 2024-bytes packets

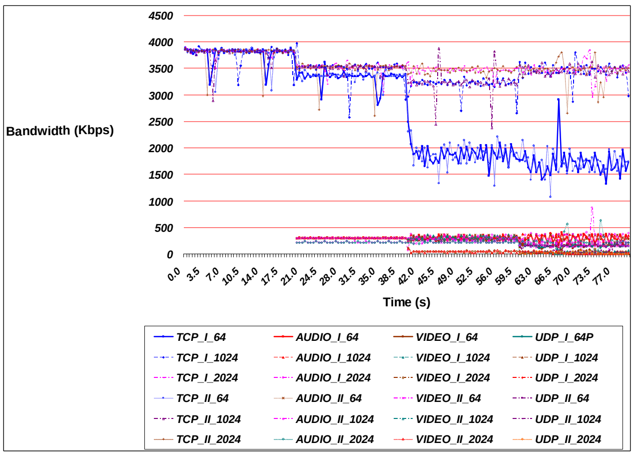


Fig. 5. Bandwidth used for the different traffic flows with HTB qdisc prioritizing the audio, and 64, 1024 and 2024-bytes packets

Fig. 5 shows the bandwidth utilized for the different traffic flows generated in scenarios 1 and 2 utilizing a HTB qdisc, prioritizing the audio. When 64-byte packets are injected into the network at a speed of 300 Kbps, they significantly affect network bandwidth in both scenarios. Network bandwidth is also reduced with packets of 1024 and 2024 bytes.

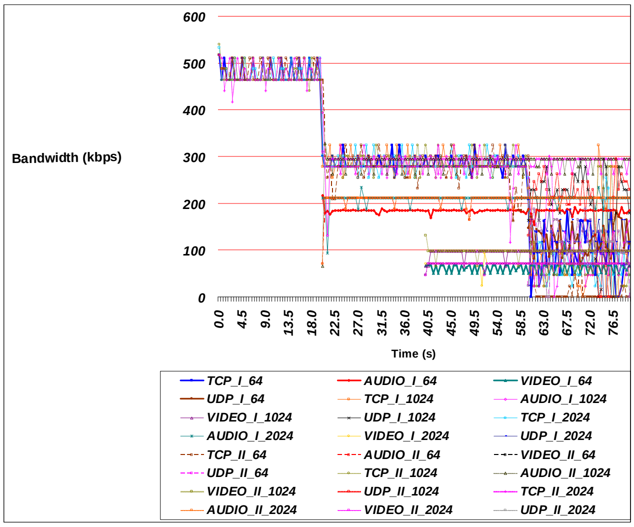


Fig. 6. Bandwidth used for the different trafficflows with DSMARK qdis and 64, 1024, 2024-bytes packets

Fig. 6 shows the bandwidth utilized for the different traffic flows generated in scenarios 1 and 2 utilizing a DSMARK qdisc. Importantly, the network performance is severely degraded because all of the packets share the same bandwidth.

Conclusions

This paper described the PANDORA protocol, based on the Hybrid Wireless Mesh Network (HWMN) architecture, for emergency and rural wireless networks. The PRIO, HTB, and DSMARK queuing disciplines were tested for TCP, voice, video, and UDP traffic in two different scenarios, and the three queuing disciplines were tested using 64, 1024, and 2024 bytes packet sizes. Results show that when QoS was not taken into account, traffic flow was not significantly affected, because PANDORA considers bandwidth use as part of its routing strategy. When the scenarios included queuing disciplines, however, PRIO and HTB prioritizing UDP performed the best. Future work will employ the PANDORA algorithm in commercial wireless routers.

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PANDORA protocol for emergency and rural wireless networks is described, which is based on the Hybrid Wireless Mesh Network (HWMN) architecture. The HWMN is an emerging two-tier architecture targeting the deployment of large-scale networks in a quick and inexpensive fashion. We test three queuing disciplines using the PANDORA protocol: PRIO, HTB, and DSMARK, with four kinds of traffic: TCP, voice, video, and UDP without marks. Results have shown that PRIO and HTB prioritizing UDP performed the best. Ill. 6, bibl. 14 (in English; summaries in English, Russian and Lithuanian).

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Описан протокол PANDORA, предназначенный для приоритетных и сельских беспроводных сетей передачи данных. Он основан на архитектуре гибридных беспроводных сетей (HWMN). HWMN – это новая двухсегментная архитектура, позволяющая быстро и недорого планировать крупномасштабные сети данных. Используя протокол PANDORA проверены три принципа составления очередей пакетов данных: PRIO, HTB, и DSMARK. Каждый из них проверен используя четыри вида потоков данных: TCP, голоса, видео и UDP данных без дополнительных марок. Результаты показали, что выделив приоритетность PRIO и HTB, наибольшая эффективность достигалась при передачи потока UDP. Ил. 6, библ. 14 (на английском языке; рефераты на английском, русском и литовском яз.).

R. A. Santos, A. González-Potes, M. A. García-Ruíz, A. Edwards-Block, V. Rangel-Licea, L. Villaseñor-González. Hibridiniai maršrutizavimo algoritmai didelio prioriteto ir kaimo vietovių bevieliuose duomenų tinkluose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 3–8.

Aprašomas didelio prioriteto ir kaimo vietovių bevieliuose duomenų tinkluose naudojamas protokolas PANDORA. Jis pagrįstas hibridinio bevielio tinklo (HWMN) architektūra. HWMN yra perspektyvi dviejų lygmenų architektūra, skirta greitai ir nebrangiai plėtoti dideliems tinklams. Pasinaudojant PANDORA protokolu išbandyti trys duomenų paketų eilių sudarymo principai: PRIO, HTB ir DSMARK. Kiekvienu atveju buvo naudojamas keturių tipų duomenų srautas: TCP, balso, vaizdo ir UDP duomenys be papildomų žymių. Rezultatai rodo, kad, teikiant prioritetą pagal PRIO ir HTB, didžiausias našumas pasiekiamas perduodant UDP srautą. Il. 6, bibl. 14 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).