

An Improved IEEE 802.11 Protocol for Reliable Data Transmission in Power Distribution Fault Diagnosis

Fabio Campoccia (fabio_campoccia@yahoo.it)

Maria Luisa Di Silvestre (marialuisa.disilvestre@unipa.it)

Eleonora Riva Sanseverino (eleonora.rivasanseverino@unipa.it)

Gaetano Zizzo (zizzo@dieet.unipa.it)

Address: DIEET Università di Palermo viale delle scienze 90128 Palermo Italia

Abstract— A high level of power quality in distribution networks is obtained by means of a diagnostic software, that on-line assesses the status of the network, by elaborating the measured data. An efficient telecommunication system is thus necessary. Upon occurrence of a fault the reliability of the distribution system depends on the security of the timely protective and restorative actions on the network. In this paper, after a brief examination of the diagnostic method, the telecommunication system is examined. For this purpose, the WiFi telecommunication system has been considered the most suitable due to its economy, although it is not adequately reliable for how it is managed by the IEEE 802.11 protocol. In this work, a new protocol derived by a modification of the IEEE 802.11 is described; the improvements which it introduces are highlighted and its capability for the diagnostic service is verified in the application section.

Index Terms— WiFi, IEEE 802.11 protocol, diagnostic, smart power distribution.

I. INTRODUCTION

Medium Voltage (MV) networks are meshed systems, with different supplying points (HV/MV stations), operated as radial systems by opening a certain number of tie-switches located at the secondary substations (MV/LV substations). By varying the tie-switches status, the network configuration is changed. This is possible both during regular working conditions and in presence of anomalies. In the first case, it is possible to control the state of the system, in order to optimize the tie-switches layout so as to reduce management costs and improve quality.

In case of anomalous working conditions or faults, safety conditions must be guaranteed both for persons and systems, by identifying the span of line in which the problem has occurred and by opening the relevant tie-switches. In this way, a configuration for service restoration is identified and implemented.

In order to carry out this management philosophy in limited times, a diagnostic algorithm, that operates the continuous monitoring of a set of electrical and not-electrical features measured at every secondary substation, has been defined in [1-3].

The algorithm is implemented in an intelligent unit which is one of the nodes of a telecommunication infrastructure. The diagnostic strategy is then carried out by the cooperation of

different intelligent units located at the MV/LV substations. In [4] and [5], different telecommunication architectures for the intelligent system diagnostic have been studied (centralized, decentralized or mixed) concluding that the most efficient structure is the mixed one. The mixed structure uses a central intelligent unit (in the HV/MV station) and local intelligent units (at the MV/LV substations), equipped with microprocessor units in which the diagnostic algorithm is loaded. In order to precisely locate and identify the type of event, each unit communicates with the others by exchanging information on the values of some electrical quantities and on the state of the system [3,4], about 1000 bits, or sending commands for the opening and the re-closure of the tie-switches, about 15 bits.

What guarantees the precision of the proposed methodology is the possibility to process under fault measurements, the hardest case for this task are the low impedance fault, for which the intervention of protections happens in the technical time required for opening.

In presence of low impedance faults, indeed, the protection device at the HV/MV station opens the line, and then re-closes, usually, after $\Delta T = 0.3s$. In this case, the values that must be sent, are those which are measured in the time between the occurrence of the fault and the opening of the protection device.

These measures are sent from one substation to the adjacent one following the reverse direction of power. The latter intelligent unit elaborates the received data, identifies the fault and locates it in the faulted span. While the line is not supplied, the upstream and downstream substations order the opening of the local tie-switches at the ends of the faulted span, isolating the latter. In this way, when the protection device at the HV/MV station re-closes, the service is partially restored, (Fig. 1).

Figure 1, indicates automated actions: either commands sent from the central unit to the tie switches or the intervention of protections.

In the proposed approach, the time interval of 0.3 seconds must be divided between the following operations:

- data acquisition and elaboration
- data transmission to the central unit
- subsequent actions.

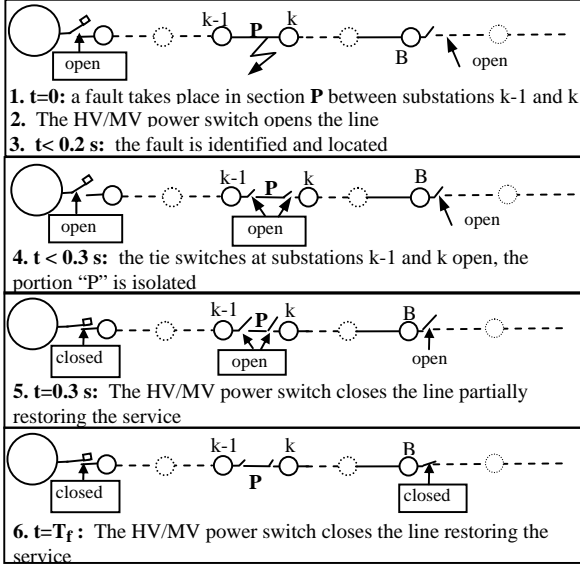


Fig. 1. Sequence of operations for identifying and isolating the fault and restoring the service.

We assume that the execution of these operations, the opening time of the tie-switches, as well as the time for sending the information and the opening command must be done in 0.15s.

The secondary substations close to the fault send the results of the diagnosis to the central unit, that elaborates the actions necessary for isolating the affected line span.

In a time T_f (about 1s), depending on the efficiency of the communication system, the central unit commands the closure of the closest boundary tie-switch, B in Fig. 1, so that the supply is totally restored.

In regular working conditions, every time interval ΔT_r , each unit sends the measured data to the other adjacent unit, which are elaborated by the diagnostic algorithm. If the latter finds a high impedance fault, the event is evidenced to the operator.

If no anomalous working condition is found, the data acquired in the considered time interval, are sent to the central unit and analyzed for determining a possible improved configuration for the network. The acquired data can be elaborated together with other historical data in order to forecast a possible deterioration of the considered span of line.

An on-line transmission between the local units and the central unit can be done by means of the power line communications or wireless technology. In particular, in this work, the WiFi system has been considered, taking into account its economy and ease of installation.

Nevertheless the WiFi systems are typically managed by the IEEE 802.11 protocol that makes it not reliable for the proposed diagnostic application that requires security in the data communication. It is well-known that in the WiFi networks the data are divided into packets sent in succession, in order to reduce the errors due to the radio channel.

The IEEE 802.11 protocol gives rise with high probability to loss of packets or delay in their transmission. Therefore it needs suitable modifications [6] for a diagnostic application, proposed in the following sections.

II. 802.11 PROTOCOL CHANNEL ACCESS

The most used channel access type is a Distributed Coordination Protocol, DCP, adopting Carrier Sense Multiple Access, CSMA. Every station, with data to transmit, checks the channel to determinate if there is a carrier. If the channel is free, the station sends its data packets (using the Mac Protocol Data Unit: MPDU). The receiving station, after retrieving the correct packet, sends back, after t_{Sifs} , an acknowledge packet (Ack) in the time t_{Ack} . If the sending station does not receive Ack before Ack-Timeout expiration, it re-transmits the packet. The retry schema allows a maximum number of retries.

The sending packet time t_p depends on the number of MPDU bits (*DATA*) and on the 802.11 transmission band V_{tra} (1, 2, 5.5 or 11 Mbit/s). The 802.11 expressions associated with t_p and t_{Ack} relative to "long preamble" are:

$$t_p = \frac{DATA + 288}{V_{tra}} + 192 \mu s \quad ; \quad t_{Ack} = \frac{112}{V_{tra}} + 192 \mu s \quad (1)$$

If more stations transmit at the same time, the packets collide. To avoid collisions, the 802.11 protocol allows that every station, after having found the channel free, waits a time t_{wait} given by:

$$t_{wait} = t_{Difs} + t_{Backoff} \quad (2)$$

The time t_{Difs} is reported in Table I; the time $t_{Backoff}$ is randomly generated, following the expression below:

$$t_{Backoff} = Random(0 \div CW) t_{Slot} \quad (3)$$

where CW is initialized at $CW_{min} = 31$, and gets a double value after every retry (if the acknowledgement procedure fails) until it reaches the maximum value of $CW_{max} = 256$. The time t_{Slot} is the elementary time interval. The WiFi physical layer uses Direct Sequence Spread Spectrum (DSSS) technology at different data rates. The times t_{Slot} , t_{Sifs} , t_{Difs} , for the most common DSSS access modality are reported in Table 1 below.

TABLE I
CHARACTERISTICS TIMES FOR THE MOST COMMON DSSS ACCESS MODALITY

t_{Slot}	t_{Sifs}	t_{Difs}
20 μs	10 μs	50 μs

Figure 2 shows the time scheme for the sending operation, standardized in IEEE 802.11. In the time indicated by the arrow 1, the station tests the channel and finds it busy. Then it waits until the time indicated by arrow 2 and it finds the channel free. So the station waits a time t_{Difs} , extracts a random value of CW (in Fig.2 $CW = 7$) and waits a time $t_{Backoff}$ calculated by the (3). $t_{Backoff}$ is reduced at every iteration of a time t_{Slot} until it becomes equal to zero and the station starts the transmission. If the channel gets again busy before the

backoff-timer reaches zero, the $t_{Backoff}$ counter is stopped and starts again when the channel is again free (after waiting a time t_{Difs}).

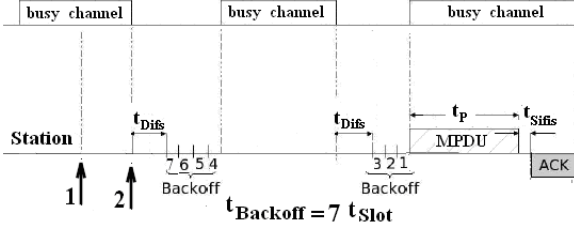


Fig. 2. Time scheme for the sending operation (IEEE 802.11).

III. COLLISION BETWEEN PACKETS IN WiFi SYSTEMS

In MV networks diagnostic analysis, the information and the tie-switches opening/closing commands (considered as data to be transmitted) have to be forwarded between and through MV/LV substations using a WiFi mesh network composed by several WiFi stations with transmission range of about 100÷150 m. Considering the most common line lengths in MV power transmission and setting M as the number of WiFi stations, possible paths for transmission are:

- about $M=3\div 20$ WiFi stations used to send data between a local MV/LV unit and the one next.
- more than hundred WiFi stations used to send data between the central unit and the local MV/LV unit.

Following the IEEE 802.11 standard, two WiFi stations, inside their transmission ranges, can get a MPDU collision if they both start the transmission in less than t_{Slot} . In this case, the second station has no time to detect the first station re-sending its data. In the proposed application, this kind of collision can happen frequently because the data are continuously sent between local units within a short time interval ($\Delta t = 0.1s$). Moreover, another disadvantage of CSMA is related to the hidden terminal case. In Fig. 3, for example, the transmission ranges of some WiFi stations are reported. Station A listens to station B. Station B listens to station A and to station C. Station C listens only to station B. If station A sends a packet to station B, it checks the channel and finds it free even if station C is transmitting. So station B receives two packets in the same time and a collision happens. In this case, station A is a “hidden terminal” for station C.

This problem becomes serious for systems with numerous WiFi stations and several MPDU packets transmissions.

Collision probability between two MPDU packets or between an MPDU packet and an ACK packet increases. Therefore using the IEEE 802.11 protocol does not guarantee a secure data transmission for the reasons described above. In the following an IEEE 802.11 protocol change is proposed to increase its reliability. Precondition is that stations transmission ranges is $Tx_range = 1$ (the transmission range includes two stations) as reported in Fig. 3. This is the most

economic condition for the choice of the number of WiFi stations.

Anyway the following considerations can be extended to any Tx_range value.

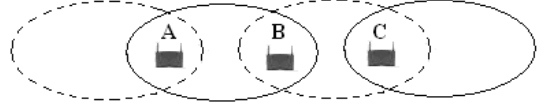


Fig. 3. Transmission ranges of three WiFi stations.

IV. PROPOSED CHANGES TO THE IEEE 802.11 PROTOCOL

The first proposed change to the IEEE 802.11 protocol allows every station to transmit MPDU (defined $MPDU_0$) with constant length packet data ($DATA_0$), sent in time $t_{p,0}$ with zero padding in case of not enough information to send. In this case, to avoid collision, under the hypothesis of $Tx_range = 1$, it is allowed that only station i and $i+3$ can transmit at the same time. In Fig. 4 it is shown an example.

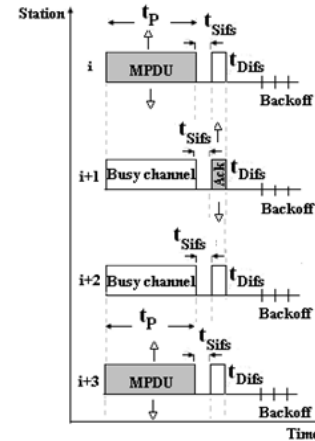


Fig. 4. First change proposed for the IEEE 802.11 protocol: stations within $Tx_range = 1$ are prevented from contemporaneous transmission.

Data packet and Ack in grey color indicate the sending station.

Because of station i interferences with stations $i-1$ and $i+1$, to avoid collisions, it can transmit only in the same time of station $i+3$ (that interferes with stations $i+2$ and $i+4$).

Looking at Fig. 5, the second protocol change is introduced: to guarantee a no collision sequence transmission, it is necessary to divide the transmission into time-frames.

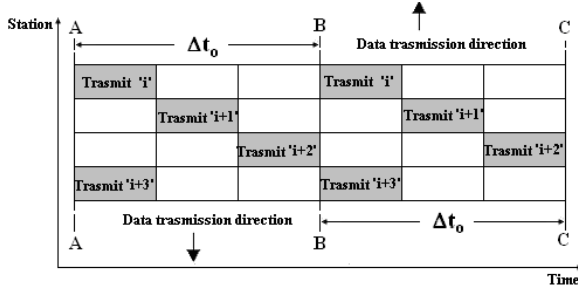


Fig. 5. Second change proposed for the IEEE 802.11 protocol: transmission is divided into time frames.

Dividing the data stream into constant time-frames of length Δt_o , the IEEE 802.11 protocol needs to adopt (third protocol change) a constant time $t_{Backoff}$ (not random as in (3)) deduced from the expression:

$$t_{Backoff,o} = CW t_{Slot} = 3CW_o t_{Slot} \quad (4)$$

where CW_o is a free parameter. Each time frame has width Δt_o given by:

$$\Delta t_o = 3(t_{P,o} + t_{Difs} + t_{Sifs} + t_{Ack}) + t_{Backoff,o} \quad (5)$$

Fig. 6 shows in details section AB of Fig. 5 and clarifies why CW has to be chosen constant and a multiple of 3.

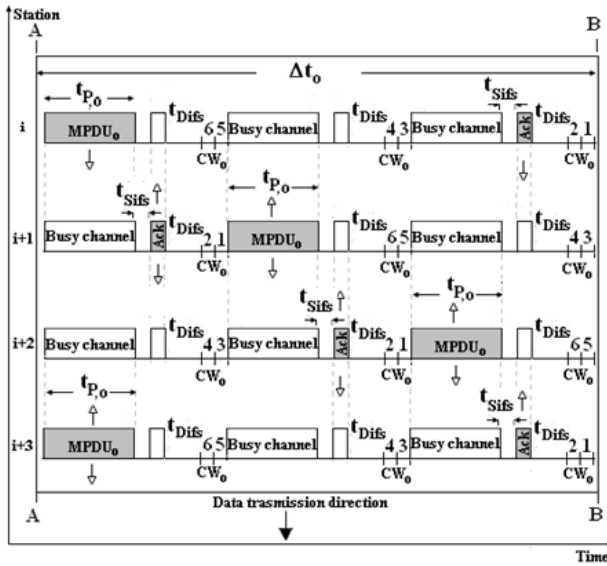


Fig. 6. Third change proposed for the IEEE 802.11 protocol: the waiting time before transmission, with free channel, is constant

In Fig. 6 it is chosen $CW_o = 6$. The operation described in Fig. 6 is not valid for stations 1, 2 and $N-1$. In fact during the interval between two consecutive transmissions:

- station 1 gets the channel busy once by station 2, while the generic station i (with $2 < i < N-1$) gets a busy channel twice, first when station $i-1$ is transmitting and second when station $i+1$ is transmitting;

- station 2 and $N-1$ get busy channel twice but for less time than generic station i .

The different behaviours of stations 1, 2 and $N-1$ makes the fourth change to the IEEE 802.11 protocol necessary: to maintain the system synchronism, stations 1, and $N-1$, have to transmit packets of different length with respect to the other stations ($DATA$). To calculate the value of $DATA_o$, $DATA_{N-1}$, $t_{Backoff,1}$, $t_{Backoff,N-1}$ from Fig. 7 and Fig. 8, the following conditions are given.

For station 1:

$$t_{Backoff,1} > t_{Backoff,o}; t_{P,1} > t_{P,o} \quad (6)$$

For station $N-1$:

$$t_{Backoff,N-1} > t_{Backoff,o}; t_{P,o} < t_{P,N-1} < t_{P,o} + t_{Sifs} + t_{Ack} \quad (7)$$

The previous conditions permit to obtain the following expressions for $t_{Backoff,1}$ and $t_{Backoff,N-1}$ (appendix 1):

$$t_{Backoff,1} = t_{P,o} + t_{Difs} + t_{Sifs} + t_{Ack} + t_{Backoff,o} \quad (8)$$

$$t_{Backoff,N-1} = 2t_{P,o} + t_{Sifs} + t_{Backoff,o} - t_{P,N-1} \quad (9)$$

These quantities have to be multiple of t_{Slot} to allow the operation of the protocol (the corresponding CW s must be integer numbers). This condition allows to deduce $DATA_o$, $DATA_1$, $DATA_{N-1}$, (appendix 2):

$$DATA_o = H_1 20V_{tra} - 444V_{tra} - 400$$

$$DATA_1 = H_1 20V_{tra} - 242V_{tra} - 288$$

$$DATA_{N-1} = 20V_{tra} (2H_1 - H_{N-1}) - 686V_{tra} - 512 \quad (10)$$

$$t_{Backoff,1} = (3CW_o + H_1)t_{slot}$$

$$t_{Backoff,N-1} = (3CW_o + H_{N-1})t_{slot}$$

where CW_o , H_1 and H_{N-1} are integer numbers chosen to validate the expression:

$$H_1 - 12.1 - \frac{112}{20V_{tra}} > H_{N-1} > H_1 - 22.2 - \frac{124}{20V_{tra}} \quad (11)$$

The above expressions are valid for transmission from station 1 to station N .

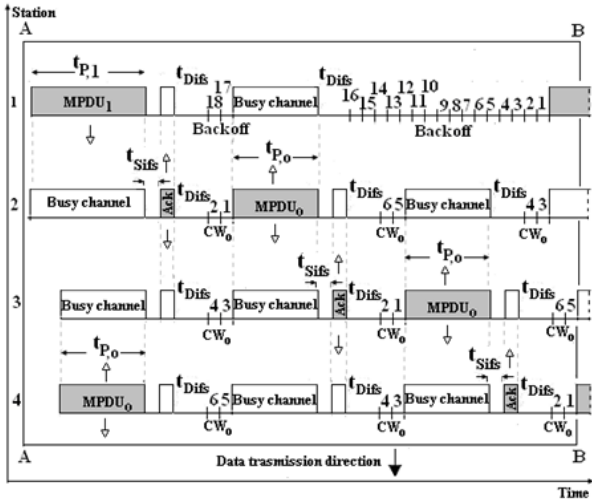


Fig. 7 Fourth change for the IEEE 802.11 protocol (stations 1÷4).

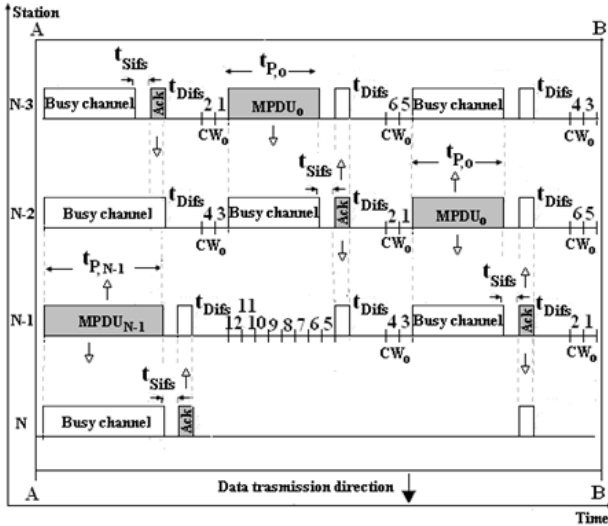


Fig. 8 Fourth change for the IEEE 802.11 protocol (stations N-3 ÷N).

To get an expression valid for transmission from station N to station 1, it is necessary to modify the indices.

V. EFFICIENCY OF THE NEW PROTOCOL

It is necessary to verify if the efficiency of the new protocol is suitable for the diagnostic management of a generic MV line made by K secondary substations and, on average with M WiFi stations between each couple of secondary substations.

The small quantity of data that must be sent in case of fault (1000 bits), allows the transmission with only one packet. Under this hypothesis, in Table II, are reported as an example the values of various parameters indicated in (4) and (8), evaluated with a transmission speed equal to $V_{tra} = 1$ Mbps. It is imposed $CW_0 = 1$ for minimizing the transmission times.

TABLE II
VALUES OF CW_0 , $DATA_o$, $t_{P,o}$ AND t_{ACK} FOR $V_{tra} = 1$ MBPS

$CW_0=1$	$DATA_o=1016$ bit	$t_{P,o}=1496$ μ s	$t_{ACK}=304$ μ s
$H_1=93$	$DATA_j=1330$ bit	$t_{P,j}=1810$ μ s	$t_{Backoff,j}=1920$ μ s
$H_{N-1}=70$	$DATA_{N-1}=1122$ bit	$t_{P,N-1}=1602$ μ s	$t_{Backoff,N-1}=1460$ μ s

Using expression (3), $\Delta T_o = 5.64$ ms is obtained.

In Table III the delay times $2\Delta T_o$ needed by a WiFi station for transmitting a packet of information are reported as function of V_{tra} , and a set of parameters are evaluated analogously to the ones indicated in Table II.

TABLE III

DELAY TIME $2\Delta T_o$ AS FUNCTION OF V_{tra}

V_{tra} [Mbps]	1	2	5.5	11
$2\Delta T_o$ [ms]	11.28	7	4.4	3.6

The opening command of the tie-switches of the secondary substation adjacent to the one that has identified the fault, implies the transmission of a small number of bits (≈ 15). Under this hypothesis, in Table IV the transmission time $2\Delta T_o$ of a command from a WiFi station to another is reported as a function of V_{tra} .

TABLE IV

DELAY TIME $2\Delta T_o$ AS FUNCTION OF V_{tra}

V_{tra} [Mbps]	1	2	5.5	11
$2\Delta T_o$ [ms]	5.4	4	3.4	3.1

The times in Table V are very close to those in Table IV because, as it is evident from (1), for the dispatch of packages with a little number of bits, the constant time for the identification of the WiFi source station are significant.

TABLE V

MAXIMUM NUMBER OF WiFi STATIONS AS FUNCTION OF V_{tra}

V_{tra} [Mbps]	1	2	5.5	11
M	9	14	20	23

When a fault occurs in a span of a MV line between two secondary substations, indicated by k and $k+1$, the transmission time of the information from the substation $k+1$ to the substation k (Table III) added to the time for the sending of the opening command of the tie-switches from the substation k toward the substation $k+1$ (Table IV), must not exceed $\Delta t = 0.15$ s. In Table V the maximum number of WiFi stations between two adjacent secondary substations is reported as function of V_{tra} . The maximum number of stations is compatible with the highest predictable distance between two substations. When a fault occurs in a span, it is necessary to establish the time T_f spent from the central unit for commanding the closing of one of the boundary tie-switches for totally restoring the service. In this case T_f is the sum of the sending time of the information to the central unit and of the time needed for the closing command sent from this to the boundary tie-switch. The information (2000 bits) is sent from one of the two substations at the ends of the faulted span (precisely the one closest to the central unit). In the hypothesis of most unfavourable position of the faulted span and of the boundary tie-switches, in Table VI T_f is reported for some values of the product $K \cdot M$ as function of V_{tra} .

Every ΔT_r the local units send the acquired data to the central unit. Within ΔT_r , K packets, as many as the secondary substations, must reach the central unit.

TABLE VI
TIME T_f AS FUNCTION OF $K \cdot M$ AND V_{tra}

V_{tra} [Mbps]	1	2	5.5	11
$K \cdot M$	T_f [s]			
50	1.1	0.7	0.4	0.3
100	2.2	1.4	0.8	0.7
150	3.3	2.1	1.2	1

In Table VII using the data in Table III, the minimum time ΔT_r , necessary for transferring the data of K secondary substations each one with M WiFi stations, is reported as function of V_{tra} .

TABLE VII
MINIMUM TIME ΔT_r AS FUNCTION OF V_{tra}

V_{tra} [Mbps]	1	2	5.5	11	
K	M	ΔT_r [s]			
5	5	1.4	0.75	0.55	0.45
	10	2.8	1.5	1.1	0.9
10	5	5.6	3	2.2	1.8
	10	11.3	6	4.4	3.6
15	5	12.7	6.7	5	4
	10	25.4	13.4	10	8

VI. CONCLUSION

A modification to the IEEE 802.11 protocol has been presented; it is necessary to ensure the reliability of the data transmission times between two terminal units, connected by many WiFi stations. The modified protocol, even if increases the transmission times, eliminates the danger of the collisions between the packets and the consequent casualty of the times necessary for their transfer. The proposed modifications have been detailed, that make the transmission no more casual but connected to a precise temporal plot. The relations presented have allowed the evaluation of the transmission times for the sending of the information or the commands varying the transmission speed of the radio channel. These results, suitably elaborated for the transmission between two secondary substations or between these and the HV/MV station, have given indications perfectly compatible with the expectations foreseen for every diagnostic situation. Further studies will address the fault tolerance and reliability of the proposed system.

VII. APPENDIX I

The value of ΔT_o for substations 1, 2 and N-1 can be obtained by examining Figs. 7 and 8:

Substation 1

$$\Delta t_o = t_{P,o} + t_{P,1} + 2t_{Difs} + t_{Sifs} + t_{Ack} + t_{Backoff,1} \quad (12)$$

Substation 2

$$\Delta t_o = 2t_{P,o} + t_{P,1} + 3t_{Difs} + 2t_{Sifs} + 2t_{Ack} + t_{Backoff,o} \quad (13)$$

Substation N-1

$$\Delta t_o = t_{P,o} + t_{P,N-1} + 3t_{Difs} + 2t_{Sifs} + 3t_{Ack} + t_{Backoff,N-1} \quad (14)$$

Comparing equations (12) and (13), the equation(8) is obtained and comparing equations (5) and (14), the equation (9) is obtained.

VIII. APPENDIX II

Combining equations (1) and (8), it is obtained:

$$t_{Backoff,1} = 444 + \frac{DATA_o}{V_{tra}} + \frac{400}{V_{tra}} + t_{Backoff,o} \quad (15)$$

To make $t_{Backoff,1}$ multiple of t_{Slot} , in equation (15) it has to be:

$$444 + \frac{DATA_o}{V_{tra}} + \frac{400}{V_{tra}} = H_1 t_{Slot} \quad (16)$$

From equation (16) $DATA_o$ is obtained.

Combining equations (5) and (13), it is obtained:

$$t_{P,1} = t_{P,o} + t_{Sifs} + t_{Ack} \quad (17)$$

Combining equations (1) and (17), $DATA_1$ is obtained.

Combining equations (1) and (9), it is obtained:

$$t_{Backoff,N-1} = 202 + \frac{2(DATA_o)}{V_{tra}} + \frac{288}{V_{tra}} - \frac{DATA_{N-1}}{V_{tra}} + t_{Backoff,o} \quad (18)$$

For making $t_{Backoff,N-1}$ multiple of t_{Slot} , in equation (18) it has to be:

$$202 + \frac{2(DATA_o)}{V_{tra}} + \frac{288}{V_{tra}} - \frac{DATA_{N-1}}{V_{tra}} = H_{N-1} t_{Slot} \quad (19)$$

IX. REFERENCES

- [1] A. Campoccia, M. L. Di Silvestre, I. Incontrera, E. Riva Sanseverino, "A new methodology for distribution systems faults identification, location and characterization", COMPEL Vol. 24, No.4, pp. 1328-1350.
- [2] A. Campoccia, M. L. Di Silvestre, I. Incontrera, E. Riva Sanseverino, "Faults identification, location and characterization in electrical systems using an analytical model-based approach". CIREN 2005.
- [3] A. Campoccia, M. L. Di Silvestre, I. Incontrera, E. Riva Sanseverino, "A generalized methodology for distribution systems faults identification, location and characterization", IEEE PowerTech 2005.

- [4] E. Riva Sanseverino, I. Incontrera, F. Campoccia, "An integrated system for efficient management of distribution networks: the system's architecture and the telecommunication infrastructure", UPEC 2006.
- [5] F. Campoccia, I. Incontrera, E. Riva Sanseverino, I. Tinnirello, "An architecture Wi-fi and GPRS for efficient management of distribution electrical networks", UPEC 2008.
- [6] I. Tinnirello, F. Campoccia, L. Scalia, "Improving IEEE 802.11 Performance in Chain Topologies through Virtual Polling and Network Coding", IEEE ICC'09 Wireless Networking Symposium.

X. BIOGRAPHIES

Fabio Campoccia (1974) received the electronic engineering degree (telecommunications) from the University of Palermo in July 2000. From September 2000 to October 2004 he worked for Ericsson TLC as system integrator and field tester in the area of mobile telecommunication systems. From November 2004 to February 2005 he worked for LG as terminal validator and field tester for mobile devices. Since March 2005 he has been working for Devoteam auSystems as test leader in the area of mobile messaging and radio networks. He has been a PhD student since November 2006 at the University of Palermo in the field of radio technologies for wireless network.

M. L. Di Silvestre (1965) in 1993 received the Master degree in Electrical Engineering at the University of Palermo, Italy. In 1998 she successfully finished her Ph.D in Electrical Engineering (Electric Power Systems) at the same University. From 1999 to 2000 she joined the Department of Electrical, Electronics and Telecommunications Engineering of the University of Palermo as a grant holder. Since 2000 she has been with the same department as a university researcher. Her main research interests are in the fields of analysis and modeling of complex grounding systems, diagnostic methodologies elaboration for the evolutionary analysis of the electrical system, power system electromagnetic compatibility and electromagnetic numerical methods.

Gaetano Zizzo (1976) received the Master and Doctor degrees in Electrical Engineering in 2002 and 2006 from the University of Palermo, Italy. He collaborates with the DIEET of the University of Palermo as Post-doc Fellow. His main research interests are in the fields of electrical safety, risk analysis, earthing systems and power systems design.

Eleonora Riva Sanseverino (1971) received the Doctor degree in Electrical Engineering from the University of Palermo, Italy, in 1995. Since 1995 she has been working in the Research Group of Electrical Power Systems. In 2000 she successfully finished her PhD in Electrical Engineering at the same University. From December 2001 to July 2002 she worked as a researcher at the University of Palermo. Since July 2002 she has been an associate professor in power systems at the University of Palermo. Her main research interests are in the fields of faults diagnostics, optimisation methods for electrical distribution systems design, operation and planning of power systems.