EAI Endorsed Transactions
on Wireless Spectrum
Research Article EAI.EU

Use of tactical radio operator’s vital signs as context information for dynamic spectrum management within MANETs

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Abstract

INTRODUCTION: The Authors present a new approach to a method of dynamic spectrum management for military mobile ad hoc network. They propose that data concerning vital signs of tactical radio operators be used as context information for spectrum management. If the operator’s inability to operate and protect the tactical radio is identified, actions (remote control of radio) are taken with the aim to release spectrum resources which used by the radio. Additionally, in this case remote control of radio allows switch the radio to modes used by search and rescue teams and lock the radio for unauthorized person.
OBJECTIVES: The primary objective of this study was use vital signs of tactical radio operator’s as context information for dynamic spectrum management within MANET.
METHODS: Tests for correct detection of vital signs were carried out for data generated on a Hal S3201 adult patient simulator. Hypotheses about radio operator's vital signs were verified by means of a belief function defined in Dempster-Shafer theory.
RESULTS: Loss vital signs by the operator allows to remote turn off his/her tactical radio while allocating more resources to other network users, which allow increasing data throughput.
CONCLUSION: Monitoring vital signs of a tactical radio operator enables detecting combat readiness loss which results in inability to protect communications and can be used in spectrum management mechanisms.

Keywords: dynamic spectrum management, MANET, combat readiness, context in-formation, remote radio control, vital signs.

Received on 31 October 2019, accepted on 12 March 2020, published on 13 March 2020

doi: 10.4108/eai.13-7-2018.163805

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1. Introduction

The current trend of dynamic development of radio communication systems calls for introducing constantly improved effective methods of radio resources control, depending on changing operational conditions, which enable optimal use of available spectrum resources and makes the communication service available to the greatest possible number of users.

The dynamic combat operations require support from highly mobile communication networks, which should ensure the ability to interact between units in on-demand fashion depending on the conditions. The decentralized mobile ad hoc networks (MANET) are essential for military applications, also due to its self-organizing ability and lack of fixed infrastructure. In the MANET, each node can act as both a terminal and a relay providing multi-hop data transmission between users. This requires quick responses to changes within the network topology for the purpose of maintaining communication between the nodes. Meanwhile, proactive routing protocols, which are recommended for networks operating in military environment [1], introduce redundant control traffic. Furthermore, it may often happen that the assigned spectrum range might not be effectively used due to a loss of vital signs by tactical radio operators. It means that the radio operator loss ability to carry out certain assignments, such as i.e. tactical radio operation and protection. Assessment of tactical radio operator's vital signs may be used as context information [2] in MANET spectrum management mechanisms.

More efficient use of the available frequency band is possible thanks to applying a new philosophy of dynamic spectrum management (DSM). DSM in MANETs may be achieved by [3]:

- centralized management, which uses a frequency broker featuring implemented spectrum tracking procedures, channel predefinition and cognitive use of the channels by those network nodes which do not have any features of a cognitive radio (CR).
- opportunistic management, where management function is dispersed between cognitive nodes (MANET-CRs).

In case of centralized management, tactical radio operation is based on DSM application of coordinated methods of spectrum management in which it is equipped. Coordinated DSM is distributed within essential dedicated frequency bands, known as dynamic coordinated spectrum access (CSA). Coordinated DSM model uses devices supporting spectrum coordination within a given geographical region for them in order to decide about spectrum access within CSA. The spectrum coordinator (SC) collects information acquired from sensors directly from a tactical radio with DSM or from other nodes which probe the environment. The data is processed for the purpose of characterizing radio environment. This information allows coordinators to be able to assign free spectrum resources in response to access requests received. The SC assigns spectrum channel to each network users with a certain time limit, which lasts to the end of a communication session. After the session channels are released and may be assigned to another users or system. The CSA supports heterogeneous users, whose requirements as to a band and operational parameters, may cause mutual interference for the remaining users. Coordinated approach is more efficient in spectrum management than any method used hitherto, because a licence for a band is granted to each user, as opposed to assigning large parts of static frequency band for use by services on a vast geographic area.

Opportunistic management involves adaptation of a frequency distribution model, in which probing of propagation environment is conducted autonomously by several tactical radios with DSM. Access to the spectrum is based on pre-defined spectrum management policies (SMPs). Tactical radios with DSM and opportunistic access capabilities recognize unused portions of frequency bands, in which they can operate without interference with primary user's communication and without violating SMPs.

DSM presents a whole range of technical problems with implementing the method. The first one is a broad range of the spectrum, which may require probing and describing its parameters. This would require tactical radios to be adjusted to detect broad frequency ranges and to be capable of transmitting and receiving throughout the entire bands. Current broadband antennas and radio technologies are still unfit for implementing that type of DSM in small radios, which could operate within broad frequency ranges. Secondly, DSM-type radios must be able to precisely detect the presence of other users within the band. If a certain band is deemed accessible by a radio, the radio must be able to collaborate with other DSM-type radios within the area in order to fulfil the requirement of not jamming other transmissions. This calls for a development of a set of policies to set out requirements for cooperation of multiple radios within a given area and frequency band.

There are many procedures for DSM use. The most important are the following procedures:

- “Command and Control”;
- “Exclusive Use”;
- “Common Spectrum Sharing”.

In case of “Command and Control” procedure a regulator grants a long-term licence for spectrum use. Such an approach is inflexible and results in unsatisfactory utilization of the spectrum resources. A slightly more flexible spectrum management method is based on temporary right to an exclusive use of a frequency band.

Dynamic “Exclusive Use” is a method involving the assignment of short-term rights to access a certain frequency band by one user of a CR network.

Another group of spectrum management method is “Spectrum Sharing” with primary and secondary users. This method is based on a detection of a possibility to use the spectrum by CR devices and on protection of primary users' transmissions against interference generated by secondary users. Spectrum sharing may be based on the detection of white spaces in primary user's spectrum and use thereof by the secondary user.

In classical solutions, the above-mentioned spectrum management methods do not consider a situation in which an operator has lost his/her vital signs (due to a shot, loss of consciousness or death). In such case, there is a situation in which a frequency band has been assigned to a tactical radio which does not utilize it. This may result in failure to assign spectrum resources to new tactical radios within the network. Hence the concept of spectrum management based on monitoring vital signs of a tactical radio operator.

2. Use of context information

There are many definitions of context information. A number of them refer to particular cases of use, such as e.g. definitions presented in [3]-[5]. A more general definition was presented in [6] by A. Dey and G. Abowd: “Context is any information that can be used to characterize the situation of entities (i.e. a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves. Context is typically the location, identity and state of people, groups and computational and physical objects.” In order to define context, one must collect adequate amount of information and to analyse it appropriately.

The possibility and benefits of using contextual information for DSM are presented in [7] and defined as context-aware DSM. [8] presents an integrated platform, called C-MIANS, that embeds interference control in standardized context-aware interoperability procedures, toward integration of context awareness into DSM, network selection, and resource allocation.

3. Vital signs as context information

In contemporary battlefield, effective tactical actions depend on reliable exchange of information and safety of soldiers. The information about soldier’s vital signs is priceless. They can be used to ensure the security of radio communications [9] and assess the tactical radio operator’s vital signs, but in this article, it will be used as context information in MANET spectrum management mechanisms.

3.1. Data acquisition

Based on literature analysis systems of mass casualty incident triage [10]-[14] and account taken of chief life- or health-threatening conditions of soldiers in combat, the following vital signs have been chosen, which enable assessing health of a tactical radio operator:

- respiratory rate;
- oxygen saturation (SpO2);
- body temperature;
- blood pressure;
- heart rate.

Abovementioned data is acquired by means of sensors placed on the body. Sensors should be of small size and weight, while their placement should not cause pain or discomfort during battlefield operations, which might sometimes last a dozen or more hours. Moreover, it is necessary for a single device to integrate already applied medical technologies.

Detection of a tactical radio operator’s adverse condition requires assessment of information based on the collected data concerning his/her vital signs. The proposed assessment mechanism uses an algorithm based on the Dempster-Shafer theory [15], while the applied detection method enables coherent and correct assessment of the operator’s condition by formulating hypotheses to enable uncertainty modelling. The process of assessing the operator’s condition considers the occurrence of factors which influence the reception of incorrect or alarming values concerning the monitored vital signs, which might not result from the operator’s worsening condition. Such factors include e.g. intensive mobility or high stress level. They have a big influence on accuracy measurements, which has a direct impact on ability of correct inference.

Due to various domains of the monitored vital signs, a pre-assessment of hypotheses is conducted separately for each of them. Assessing each parameter separately makes it possible to formulate primary hypotheses (“correct”, “life-threat”, “serious”) and secondary hypotheses (“uncertain serious”, “uncertain life-threat”, “uncertain”). Assigning a hypothesis to measurement bases on an assessment, which takes into consideration:

- a determination of a measured value range;
- values which correspond to individual operator’s features based on his/her age, sex, and vital signs normative range;
- information on the activity of the operator.

The measurement information is considered together with weights which depend on the time of observation of a given event. It allows to faster detection of changes in the soldier’s condition is possible.

A final assessment of the soldier’s health condition requires aggregated information about all the monitored vital signs. Combining the assessment of different vital signs is possible by applying the application of combination rules. Because of flaws of the commonly applied Dempster rule [16], in case of a conflict of data and if the values of some hypotheses described in [17] and [18] are approximated as zero, the combination rule described in [19] was used.

For a faster detection of adverse conditions, apart from combining assessments concerning all the vital signs, also assessments concerning parameters are combined. A selection of parameters’ combination results from situations which have been identified by medical practitioners as particularly dangerous and which are characterized by certain tendencies in vital signs, such as:

- decline in oxygen saturation combined with decline in mean arterial pressure (MAP[†]) value at rest and during activity in normal conditions;
- decline in heart rate combined with decline in MAP value at rest and during activity;
- increase in heart rate combined with decline in MAP value at rest and during activity;
- increase in heart rate combined with decline in SpO_2 value at rest and during activity;
- decline in heart rate combined with decline in SpO_2 value at rest and during activity;
- increased respiratory rate combined with decline in SpO_2 value in normal resting conditions.

[†]The MAP approximate value is estimated in accordance with [8] as:

$$MAP = DP + 1/3(SP - DP) \qquad (1)$$

where:
DP – diastolic pressure,
SP – systolic pressure.

Finally, based on an assessment of the operator's condition arrived at based on the inference process, his/her health classification is made. The operator's condition is classified as:

- serious;
- life-threatening;
- normal.

Tactical network node's classification takes place depending on a hypothesis verification. Hypotheses are verified by means of a belief function defined in Dempster-Shafer theory [15].

3.2. Detection of and response to adverse events

The decision should be made as an adequate response to detection of a tactical radio operator's adverse condition. The proposed algorithm is based on the following input data set:

- a tactical radio operator's health condition;
- interaction with a tactical radio operator;
- a tactical radio operator activity description.

and results in a set of output information, which include:

- indication of a suggested response;
- current situation, including the operator's condition, his/her activity and possible additional indicators, e.g. concerning the reported alert;
- the last known location of the tactical radio.

The commander is equipped with the module supplying visual information of the soldiers' location and information on their current status. The module enables selecting a final response for a given operator. Response actions enable controlling tactical radio's working parameters, which include e.g.:

- change of selected radio data parameters (e.g. transmitting power, operational frequency) for pre-programmed channels;
- change of a channel or tactical radio mode of operation;
- change of operator's personal settings, e.g.: loudness, brightness, contrast of display,
- removal of cryptographic keys implemented in the tactical radio,
- disabling and removal of mission plans fed into the tactical radio;
- enabling mission plans fed into the tactical radio.

3.3. Tests and exemplary outcome

Tests for correct detection of adverse conditions were carried out for data generated on a Hal S3201 adult patient simulator by Gaumard concerning predicted changes of vital signs parameters in five scenarios:

- a shot;
- hyperthermia;
- a shot accompanied by cardiac arrest;
- hypothermia;
- a shot accompanied by hypothermia.

The data include changes in the parameters of pre-set vital signs (heart rate, temperature, respiratory rate, oxygen saturation, blood pressure) with one-minute frequency. For each scenario, the emergency services indicated the expected time range, in which a harmed person's loss of consciousness might occur. Those ranges are presented in Table 1.

Table 1. Estimated time of losing consciousness by a harmed person under adverse conditions scenarios

Scenario	Loss of consciousness [min]
A shot	42 – 47
Hyperthermia	51 – 60
A shot with cardiac arrest	42 – 46
Hypothermia	44 – 47
A shot with hypothermia	36 – 40

The tests have been carried out taking into account all the indicated vital signs, information about age and sex of the volunteers and information defined based on literature analysis [20-28] of alert ranges and given critical values of particular vital signs (Table 2).

Table 2. Exemplary alert and critical values of vital signs considered in the tests

Vital sign	Alert value	Critical value
Heart rate [20][21]	40÷50/min 120 – (205.8 – (0,685*age))/min	<40/min > (205.8 – (0,685*age))/min
Temperature [22]	35,0°÷36,0°C 38,0°÷39,1°C	<35,0° >39,1°C
Respiratory rate [23][24]	9÷12/min 20÷25/min	<9/min >25 min
Blood pressure [23][24]	MAP 60÷75 mmHg SP 75÷91 mmHg SP 219÷249 mmHg	MAP<60 mmHg SP <75 mmHg SP>249 mmHg
SpO_2 [25][26][27][28]	91÷95% >99%	< 91 %

Table 3 presents the time ranges of harmed person's health condition classification under each test scenario. The Table presents the range of time of classifying the conditions as life-threatening and serious. Based on this values and information on operator activity, each of the monitored parameters values is assigned a hypothesis:

“correct”, “life-threat”, “serious”, “uncertain serious”, “uncertain life-threat” or “uncertain”. Then the operator’s condition is classified used Dempster-Shafer theory.

Table 3. Test results – time range of classifying harmed person’s condition as life-threatening and serious

Scenario	Classification of condition as life-threatening [min]	Detection of serious condition [min]
A shot	–	23
Hyperthermia	28	45
A shot with cardiac arrest	–	20
Hypothermia	–	29
A shot with hypothermia	–	20

Based on the results presented in Table 3 one can observe that under all the scenarios the adverse condition was detected before the detection of loss of consciousness. In case of tests conducted with the data originating from healthy people at rest and during activity, in no instance had the adverse condition been mis defined. Additionally, the algorithm was checked for data originating from tests conducted by Polish Rescue Centre Ltd., on 16 volunteers. The data include signals concerning heart rate, blood pressure, saturation, body temperature and respiratory rate of healthy people at rest and during activity. In case of tests conducted with the data originating from healthy people at rest and during activity, in no instance had serious condition been detected.

An appropriate analysis of the data will enable correct assessment of the operator’s health and the detection of a condition which makes it impossible for the operator to handle and protect the tactical radio. This context may be used in a mechanism of DSM within MANET. If, during a military operation, adverse condition is detected in a tactical radio operator, i.e. if it is detected that he/she has lost control of the tactical radio, it is possible to disconnect the tactical radio from the network, or to switch it to another mode of operation while releasing spectrum re-sources used by it. This is possible by remote control of the tactical radio by a commander who makes such a decision based on the data received concerning the vital signs of operator.

4. Verification of the use of contextual information

The goal of research was to verify a possibility of spectrum management within MANET based on information on tactical radio operator’s vital signs.

4.1. Research environment

The research was conducted with the use of Harris’s AN/PRC-117G tactical radios. They are multiband combat-net radios used currently in many regions worldwide, which enable operation within the frequency range from 30MHz to 2000MHz. The AN/PRC-117G tactical radios are capable of operation in narrowband modes – 12,5kHz or 25kHz – and wideband modes – up to 5MHz. Wideband mode is used by adaptive networking wideband (ANW2C) waveform. MANET is made up of tactical radios operating in ANW2C mode. This mode enables simultaneous transmission of data and voice within a radio channel. Data transmission within ANW2C network is based on IPv4 communication protocol. The maximum number of nodes in the ANW2C network declared by the radio manufacturer (L3 Harris) is 30. In our tests, we used 2 to 5 radio. ANW2C mode uses time division multiple access (TDMA) as a medium access method. ANW2C network may operate in two modes, namely with a fixed capacity allocation among all the users or in dynamic capacity allocation (DCA) mode.

4.2. Results

The presented method of assessing tactical radio operator’s combat readiness may be used to control the work of radio network nodes. In case of AN/PRC-117G tactical radios one can use a set of commands recorded in ASCII format for this purpose. Tactical radio operation may be controlled locally or remotely.

If a tactical radio operator loses combat readiness and tactical radio control as a result of a military action, such a tactical radio may be excluded from the network or switched to another mode of operation, thereby releasing spectrum resources it has hitherto used.

The figure 1 presents the results of research which illustrate an average data throughput for ANW2C network depending on several active network nodes. The research involved building an ANW2C network composed of 5 AN/PRC-117G tactical radios. One tactical radio was connected to a hypertext transfer protocol (HTTP) server, and the remaining four tactical radios operated as HTTP clients. Data throughput was determined as the ratio of the downloaded file size [kb] to the download time [s]. Figure 1 shows the average value for 20 measurements. The research was conducted account taken of two scenarios, i.e. with DCA mode enabled and disabled.

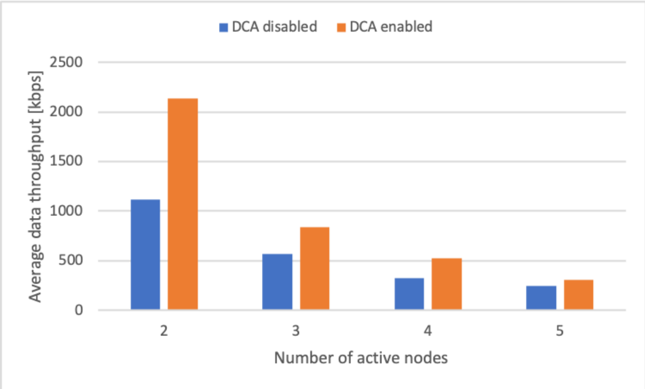

Figure 1. 5MHz ANW2C End-to-end average data throughput [kbps].

In both cases, an increase in the number of network nodes results in a division of available spectrum (available bandwidth 5MHz) among a greater number of users, which translates into a decrease in average data throughput. The DCA mechanism checks if there are inactive nodes in the network and then allocates smaller resources to them while increasing the resources for others. With a small number of active nodes (and fixed network size = 5 nodes) we notice the advantages of DCA. When the number of active nodes is equal to the size of the network, the differences between DCA enabled and disabled are small.

5. Summary

The article presents the use of information about tactical radio operator's combat readiness as context information which can be used in DSM mechanisms within MANET. The results obtained confirm a potential capability of the proposed solution to be used for spectrum management within networks which operate based on opportunistic spectrum access.

The solution presented may be used additionally to increase the security of military communications. Monitoring vital signs of a tactical radio operator enables detecting combat readiness loss which results in inability to protect communications. This is particularly important when using Type 1 radios which enable transmitting NATO TOP SECRET information. If such tactical radio is no longer protected, it must be excluded from the network, including deletion of all the tactical radio settings (encryption keys, mission plans). Moreover, constant monitoring of a tactical radio operator's vital signs enables detecting a case of unauthorised takeover and adversary usage of previously authorised means of communication.

Acknowledgements.
This article has been prepared under a project funded by the National Centre for Research and Development under a scientific research programme for state defence and security „Future Technologies for Defence – a Contest for Young Scientists".

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