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Multichannel admission control for military training network

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Abstract— A military training radio network requires support for a large number of mobile nodes with heterogeneous traffic and real-time requirements. We propose a deterministic protocol and an admission control using real-time analysis for a centralized radio network with a multichannel base station. The admission control implements an algorithm for frequency allocation to mobile nodes, and guarantees timely treatment of real-time traffic. The proposed online heuristic frequency allocation algorithm is compared to other known heuristic algorithms: round robin over channels and fill one channel first. The goal with the heuristic algorithms is to maximize the number of supported mobile nodes. Our results show that when the high utilization part of the traffic have shorter deadlines it is advantageous to differentiate different types of nodes onto separate frequencies, whilst if the deadline is increased it is advantageous to mix different types of nodes on each frequency.

Keywords—Military training radio networks; real-time guarantees; admission control; EDF scheduling; MAC; multichannel

I. INTRODUCTION

Military training systems are dependent on the radio network for efficient and seamless delivery of the data from the training field in near real-time (RT) for presentation in the exercise control center (EXCON), without compromising the realism during the military combat training. To support these requirements a radio network that support heterogeneous traffic with RT demands is preferable. The most common radio systems for military training systems are centralized with a two-way communication between a base station and up to thousands of mobiles transceivers. A full scale radio network can consist of several base stations for better coverage, a network controller, a backhaul network and EXCON, the presentation facility. Existing systems are commonly using time-slotted proprietary protocols utilizing military spectrums in the lower part of the ultra-high frequency (UHF) range. These systems have been designed for short data packets with very low data rate mostly for collection of training data where laser based weapon simulators are used instead of live firing during combat training. New trends in next generation military training radio networks are multimedia streaming and requirements for lower latency. The lower latency enables increased functionality, for example non line of sight weapon engagement simulation, increasing reliability and possibly

decreasing simulator costs. These emerging requirements, together with the existing requirements, including that of a large number of nodes, points towards the exploitation of a multichannel solution with RT guarantees.

In this paper, we propose a solution on how to maximize the number of accepted single transceiver mobile nodes with different requirements of data, voice and video transmission in a multichannel centralized military training network with the use of heuristic based frequency allocation algorithms (FAAs). The mobile nodes are supported by a single base station utilizing multiple frequency channels and a network controller responsible for the traffic scheduling. The mobile nodes are assumed to use single half-duplex frequency-tunable transceivers. The nodes have different traffic patterns; in addition to required up- and downlink for training data a fraction of the nodes have voice and/or video uplink streams. The proposed solution consists of a deterministic medium access control (MAC) with an admission control (AC) mechanism that uses RT analysis. The AC is also responsible for the frequency allocation to the nodes. Several heuristic FAAs have been evaluated for maximizing the number of accepted mobile nodes with different traffic patterns. The network traffic consists of training data, voice and video streams with hard-real time (HRT) guarantees and best effort (BE) traffic. An earliest deadline first (EDF)-based scheduling method is used for the radio resources with a strict priority queue structure supporting both HRT and soft-real time (SRT) traffic, but also a first in first out (FIFO) sorted non-RT (NRT) queue for BE traffic. The performance of the proposed solution is evaluated by simulation. The average number of supported nodes with different HRT traffic patterns in a multi-frequency base station is determined for a proposed FAA and two reference FAAs.

In previous work AC with RT guarantees for a military training network with one frequency channel has been presented [1], which was based on the adapted processor demand function [2] and RT analysis [3-6]. However, the requirements on scalability and support for RT traffic have led to the exploration of a RT analysis for a centralized network with a base station using multiple frequency channels and single transceiver mobile nodes. Several multichannel solutions have been proposed targeting RT support [7-9], for multihop network architecture. Out of these, only one solution

[7] uses a centralized architecture. In [10] a centralized scheduling algorithm is proposed for a multichannel WiMAX architecture with a single transceiver for each mobile node, but however without RT support. In this paper an AC is proposed for a multichannel radio network using a heuristic FAA, targeting to maximize the number of mobile nodes with single transceivers, and a RT analysis to support timing guarantees together with a deterministic resource handling protocol.

The main contributions of this work are: (i) a deterministic MAC protocol with an AC using FAA and RT analysis for a multichannel radio network, providing QoS and RT guarantees for single transceiver mobile nodes with different types of heterogeneous traffic requirements, (ii) evaluation of a proposed heuristic FAA along with two reference heuristic FAAs. The proposed algorithm performs better and accepts a larger average number of nodes when using shorter deadlines for the high-utilization traffic in a multichannel configuration.

The remaining paper is structured as follows. In Section II, the system model is presented consisting of a network and a traffic model as well as the multichannel resource handling mechanism. In Section III, the AC is presented together with FAAs and the RT analysis. In Section IV, the performance evaluation is presented and the results are discussed. Section V concludes the paper.

II. SYSTEM MODEL

A. Network model

A centralized radio network with a single base station utilizing C frequency channels is considered in this work. The base station has an integrated network controller responsible for the scheduling of the traffic in the network. Each mobile node has one transceiver, while the base station has one transceiver for each frequency channel. All transceivers including the base station transceivers are of half-duplex type meaning that they can either transmit or receive at any time instance. The mobile nodes are only communicating with the base station; any mobile node to mobile node communication is relayed via the base station once it has been scheduled by the network controller. All nodes are assumed to be within the coverage area of the base station.

The resource handling method is a deterministic split phase protocol where control and data transmissions are performed on the same channel (fig. 1). The transmissions are organized in superframes, each of duration T_{cycle} . The split phase protocol is used and the superframes are synchronized for all the frequency channels. Two kinds of dynamic scheduling mechanisms are assumed for uplink, a control packet (CP) based scheduling mechanism that handles sporadic traffic with minimal inter-arrival times and a non-CP based scheduling mechanism that handles periodic traffic with short latency.

Fig. 1 Superframe structure

In the CP based mechanism every mobile node is deterministically, in node number order, transmitting a CP containing information about its queue status to the base station. $T_{control,c}$ is the duration of time where CPs are transmitted over channel c and depends on the number of nodes currently accepted for each frequency channel. A feasible schedule is generated by the base station based on the received transmission requests and the schedule is broadcasted during the feedback phase, of duration $T_{feedback}$, to all mobile nodes. Finally, the scheduling is executed and followed by all nodes in the data transmission phase, T_{data} .

The non-CP based mechanism that handles periodic traffic is not suffering from a CP turnaround delay since the base station is periodically generating packet-scheduling requests based on the known traffic parameters. Slot assignments are scheduled and the information is dispensed in the feedback phase in the same way as for CP based scheduling.

According to the description of the superframe structure, the amount of time utilizable for data transmission T_{data} during one cycle for a frequency channel c , where $1 \leq c \leq C$, is

$$T_{data,c} = T_{cycle} - T_{control,c} - T_{feedback} \quad (1)$$

B. Traffic Model

A set of traffic classes h and node types k , (Table I) has been defined based on a typical training network application and the emerging requirements for the training network [1]. The traffic classes are classified based on the direction of the data, if it is uplink or downlink, and if the traffic classes can have short deadlines since these parameters have implications on the scheduling of the traffic.

All nodes in the network have a strict priority queueing structure consisting of three queues for RT and NRT traffic. The first queue, with the highest priority, is an EDF-sorted HRT queue, the second queue is an EDF-sorted SRT queue and the last queue is a FIFO-sorted NRT queue.

The queues are served with the highest priority first, exhaustive priority scheduling of queues, and only when this queue is empty a lower priority queue will be served, where the NRT is served last. All traffic with RT requirements is considered as HRT in order to guarantee their timely delivery. The remaining bandwidth can be used by SRT or NRT traffic through their respective queues. The traffic in the base station

TABLE I. TRAFFIC CLASSES

Traffic Class h	Traffic model		Node Type k			
	Type	Classification	1	2	3	4
$h=1$	Uplink, CP	Uplink, HRT	X	X	X	X
$h=2$	Downlink Non-CP	Downlink, HRT	X	X	X	X
$h=3$	Voice Non-CP	Uplink, Short deadline, HRT	X		X	
$h=4$	Video Non-CP	Uplink, Short deadline, HRT	X	X		
$h=5$	Best-effort	Uplink, Downlink, NRT

Fig. 2 AC general structure

queue will consist of downlink traffic and transmission requests for uplink traffic.

III. ADMISSION CONTROL

A. General Structure

The AC (fig. 2) is used to accept a newly arrived node in the network. It consists of a FAA for frequency channel allocation to the newly arrived node and a RT analysis for testing the node for acceptance to the channel. This is done by allocating a frequency channel c to the node j and then performing a RT test to guarantee the HRT traffic for the newly arrived node in the channel, while maintaining the guarantees for already admitted HRT traffic for the same channel in the network. Our objective is to design an AC algorithm that maximizes the number of mobile nodes, with heuristic based FAAs, while meeting their RT requirements.

The set of available channels is C_{all} and the number of available channels is $C = |C_{all}|$, while c is the index of a particular channel.

B. Real-time analysis block

The RT analysis algorithm for a multichannel base station is used to guarantee the timely delivery of all HRT traffic for the accepted nodes and is based on RT analysis for EDF scheduling.

A RT channel (RTC) is defined as a traffic flow generating instances, i.e. messages over time according to the traffic specifications. Assuming the base station have node number zero and the traffic is either uplink or downlink, a RTC i is then denoted τ_i with the following traffic parameters: source node $j_{s,i}$, destination node $j_{d,i}$, period for periodic traffic p_i or minimum interarrival time for sporadic traffic, message length

L_i , and end-to-end delay bound D_i . Given a total number of Q RTCs, each one is specified as $\tau_i = \{j_{s,i}, j_{d,i}, p_i, L_i, D_i\}$ with $1 \leq i \leq Q$.

A message L_i can be divided into several data packets depending on its size. The system can support data packets with different sizes and the total transmission time of a packet with traffic class h is $T_{packet,h}$ including payload L_{data} , interframe space T_{IFS} and header duration L_{header} (2). R denotes the data rate.

$$T_{packet,h} = \frac{L_{data} + L_{header}}{R} + T_{IFS} \quad (2)$$

We define queuing deadline, d , as the traffic deadline subtracted by the worst case delay incurred by the protocol and the specific scheduling mechanisms. The queuing deadline d is then the part of the deadline (delay bound) left for actual data transmission, i.e. the queuing time when waiting to be served in the data phase of the superframe, including the actual transmission time. The worst case delay for the CP based scheduling mechanism occurs when a data packet is generated in the node having the first slot in the control phase just as the CP has been transmitted. The node then has to wait a whole superframe cycle until the next CP transmission for informing the base station about its queue and also the entire control phase and the feedback phase until transmission of the data packet can occur in the first slot of the data phase. The worst case delay for CP based traffic for frequency channel c is given by (3).

$$T_{constant_c} = T_{cycle} + T_{control,c} + T_{feedback} \quad (3)$$

The maximum queuing deadline d for the CP based traffic for channel c is obtained, by subtracting the traffic deadline with the worst case delay, according to (4).

$$d_{CP,i,c} = D_i - T_{constant_c} \quad (4)$$

The worst case delay for the non-CP based scheduling mechanism occurs when a data packet is generated just after the start of the last useable data slot in the data phase. The node then have to wait for a whole control and feedback phase until the first data slot in the data phase where the node can transmit the data packet. The total delay adds up to the last useable data slot, the control phase, the feedback phase and also the last part of the data phase that may be just a fraction too small to be used for transmission. The worst case delay for non-CP based traffic from traffic class h for RTC i in frequency channel c is according to (5).

$$d_{Non-CP,i,c} = D_i - 2 \cdot T_{packet,h} - T_{control,c} - T_{feedback} \quad (5)$$

The HRT data arriving to the base station queue are scheduled in the global HRT queue according to EDF.

The RT analysis adheres to three constraints that have to be passed by every newly arrived node for acceptance to the allocated channel. The nodes are assumed to have a number of

RTCs, each for a different traffic class, depending on the node type according to Table I.

Constraint 1 is a utilization test where the sum of the individual RTC utilization $U_{HRT,c}$ for channel c , shall be less than the total available bandwidth $U_{HRT_Max,c}$ for the same channel. The total available bandwidth is determined by the usable part of the data phase $T_{data,c} - T_{packet,h,c}$ for the channel, where the last data slot may be too short and is deducted as a margin. Since we support traffic with arbitrary traffic parameters, i.e. with deadlines not equal to periods, the utilization test constitutes merely a necessary, but not sufficient test. The first constraint is formulated as:

$$U_{HRT_Max,c} \geq U_{HRT,c} \quad (6)$$

Constraint 2 is a combined workload and delay check that sums the workload starting from $t=0$ up to an upper bound L and simultaneously checks that all deadlines for the traffic are met. The delay and workload check function is adapted [2] from the processor demand function used in the RT feasibility test for hybrid task tests in uniprocessor scheduling [3-5]. For more details see our previous work for a single frequency channel [1]. The time instances that are checked are the traffic deadlines. The test is done for C_{all} , and for all RTCs belonging to nodes accepted by those channels.

$$h_c(t) \leq g_c(t) \quad \forall t \geq 0 \quad \forall c \in C_{all} \quad (7)$$

Constraint 3 must be fulfilled by nodes with CP based RTC traffic where $Q_{CP,j}$ denotes the subset of RTCs with CP based traffic for node j . It checks that the possible number of packets in the queues of a node that shall be informed about in a CP to the base station is not more than there is room for in the CP, β .

$$\beta \geq \begin{array}{l} \text{Queue population information for} \\ \text{node } j_{s,i} \text{ in each control packet} \end{array}, \quad (8)$$

$$j_{s,i} > 0 \quad \forall i \in Q_{CP,j}$$

These three constraints test utilization, workload and delay as well as the CP size limit for the traffic using CPs. The first test should always be run first in order to not run the more computationally heavy second test for an over-utilized system.

C. Frequency allocation block

The FAA can be of two types, online or offline. The online FAA can handle a dynamic node request order and exemplifies a network in the startup phase where no nodes yet have been accepted or a network with arriving nodes where some nodes already have been accepted. The offline FAA requires a static case, where all information about nodes is known, to achieve the intended result. It can also exemplify a system where the system do not have enough free resources to admit any more nodes, but where an offline algorithm is used to possibly reschedule all already admitted mobile nodes to enable acceptance of additional nodes. In this paper we focus on online algorithms.

We present three online heuristic FAA algorithms with the objective of maximizing the number of mobile nodes. The

FAAs can be described in this general way: a frequency channel c from C_{all} is allocated to the first node $j=1$ for RT test. The node to frequency channel allocation is continued according to the specific FAA until a node is rejected by the RT analysis. In this case the next frequency among the set is tested until the node is accepted by the RT analysis or the RT analysis has rejected the node for all frequency channels in which case the algorithm will stop.

Algorithm 1: (Round robin over frequency channels)

Every new incoming frequency channel request for a new node is allocated a frequency channel c , $1 \leq c \leq C$, according to $c_{new} = \text{mod}(c_{current} + 1, C)$ and $c_{new} = C$ if c equal to *zero*, starting with frequency channel $c_{current} = 1$ for the first node only.

Algorithm 2: (Fill one channel first starting from channel 1, and always recheck every channel from 1 to the latest allocated channel)

Every new incoming frequency channel request for a new node j is allocated a frequency channel $c_{current} = 1$. If node j is rejected by channel $c_{current}$ then allocate a new channel $c_{new} = c_{current} + 1$ only if $c_{new} \leq C$, until the node is accepted.

Algorithm 3:

This algorithm (fig. 3) will differentiate node types onto separate frequency channels as far as possible and start to mix node types, when there are no more free frequency channels available, in a way so that frequency channels with least free resources are allocated first. When node types are mixed, it is allowed only in order of decreasing utilization node types for each channel.

Initialization: The value $A_{c,accept}$ is the only node type channel c will accept. It is assigned the first time a frequency channel c is accepting a node j with type k , $A_{c,accept} = k$.

Step 1: For every new incoming frequency channel request for a node j with type k , check if a frequency channel $c \in C_{all}$, exist such that $A_{c,accept} = k$. If a frequency channel c fulfilling the requirements exists and has not been allocated to this node previously, allocate this frequency channel to node j . If several channels exist, select the channel in increasing order of channel index.

Step 2: If a node j with type k is rejected by the RT analysis from an allocated frequency channel c where the node type acceptance level was matching $A_{c,accept} = k$, then if $A_{c,accept} < 4$ update the acceptance level for channel c with $A_{c,accept} = k + 1$.

Step 3: If there does not exist any frequency channel $c \in C_{all}$ that fulfills $A_{c,accept} = k$ for node j , then allocate an unused channel c to node j and set $A_{c,accept} = k$, if there exist any unused frequency channel, i.e. $C_{unused} \neq \emptyset$, where C_{unused} is the set of unused frequency channels. (Step 3 requires that Step 1 is not fulfilled)

Step 4: If there does not exist any frequency channel $c \in C_{all}$ that fulfills $A_{c,accept} = k$ for node j , and there do not exist any unused frequency channel, i.e. $C_{unused} = \emptyset$, then sort all frequency channels C_{all} in order of decreasing A_c , which denotes the number of accepted nodes for frequency channel

c . The sequence of sorted frequencies is denoted as $f_{sort} = \{c_1, \dots, c_C\}$ where $A_{c_1} \geq A_{c_2} \geq \dots \geq A_{c_{C-1}} \geq A_{c_C}$. Now, for every new incoming frequency channel request for a new node j with type k , allocate a frequency channel $c_{new} = f_{sort}(a)$ to node j in the following sequence $a = 1, \dots, C$ until the node is accepted by the RT analysis.

Step 5: If node j cannot be accepted after step 4 there is no capacity to accept this node by any frequency channel $c \in C_{all}$.

Our proposed FAA 3 is an online algorithm but is mimicking FAA 2 when it is being used as an offline algorithm. The reason is that FAA 2 also achieves a separation of different node types onto different frequency channels as far as possible, when all nodes and their types are known before hand and are sorted according to decreasing utilization.

Fig. 3 Algorithm 3 flow chart

IV. PERFORMANCE EVALUATION

In this section the performance evaluation is described and the results are discussed.

A. Simulation assumptions

The network is assumed to consist of one base station with several frequency channels, an integrated network controller responsible for the scheduling, and a number of mobile nodes. The numerical values shown in Table II for different traffic classes have been used.

Each CP has a transmission time, T_{CP} , of $196 \mu s$ that corresponds to a payload of 320 bits. The CP can contain information about $\beta = 30$ queue packets per node. The duration of the control phase for frequency channel c assuming N nodes is:

$$T_{control,c} = N \cdot T_{CP} \quad (9)$$

The duration of the feedback phase, $T_{feedback}$, is 1 ms and the superframe duration T_{cycle} is determined during the evaluation and will also depend on the number of nodes. Each RTC traffic flow starts with a random offset from the starting time with a uniform distribution between zero and its period.

The physical channel is assumed to have a data rate R of 11 Mbps with parameters inspired by IEEE 802.11b. The message lengths are expressed as packet transmission times over this channel.

The voice and video traffic specifications are presented with deadlines dictated by the codecs and relaxed by buffering in the network for different levels of interactivity. The voice traffic specification is based on the G.723.1 codec and requires a 6.3 kbps data rate with 24 byte raw data packets at a periodicity of 30 ms. The video traffic specification is based on a video stream of 360 kbps. Assuming a periodicity of 30 ms the raw data packet size shall be 10800 bits. Each second, a fixed number of equal-sized video frames are assumed to be generated and transmitted, each within one video packet. If buffering is assumed for the voice and video data streams the traffic deadline can be relaxed to 200 ms. This allows for a lower degree of interactivity experience compared to the 30 ms deadline, but provides more freedom for the scheduling.

TABLE II. TRAFFIC SPECIFICATION

	Traffic classes h				
	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$
Type	Uplink CP	Downlink NonCP	Voice NonCP	Video NonCP	Best- effort
Direction and RT type	Uplink HRT	Downlink HRT	Uplink HRT	Uplink HRT	Uplink Downlink NRT
Period p_i [ms]	200	100	30	30	-
Deadline D_i [ms]	200	100	30 - 200	30 - 200	-
Message length L_i [ms]	0.2	0.2	0.2	1.1491	-
Payload L_{data} [bits]	360	360	360	360*30= 10800	-

Our experiments are done as follows. Nodes arrive to the network dynamically one after another. Probability of a node to be of type k is ρ_k . One experiment stops when the AC algorithm rejects the new node. The average of 1000 experiments for each studied set of parameters is used unless otherwise stated.

The performance evaluation is divided into the three subsections (B-D). First in (B) we evaluate the three algorithms separately for a typical military training scenario with 10 frequency channels. We vary the duration of the superframes and find the values that can accept a maximum number of nodes for each algorithm. Then in (C and D) we compare the performance of the three algorithms for a wider set of input parameters, such as number of frequency channels and node type proportions, for the fixed superframe lengths obtained in (B).

B. Results for different superframe lengths

The different FAAs performances are investigated in terms of maximizing the average number of accepted nodes for different superframe lengths and also different deadlines for voice and video traffic. The number of used frequency channels is 10. The evaluation is presented in fig. 4-6 and the experiments are conducted only once. Based on this evaluation the FAAs are compared in Table III with a larger number of runs to obtain the average number of accepted nodes. The superframe duration values are selected from the range of superframe durations with the highest number of accepted nodes from the initial evaluation in fig. 4-6.

The node type arrival probability is $\rho_1=1\%$, $\rho_2=9\%$, $\rho_3=9\%$ and $\rho_4=81\%$. This is a scenario that models a future military training network scenario with voice and video.

FAA 1 and 2 performs similarly while varying voice and video deadline as well as superframe lengths as can be seen in fig. 4-5. FAA 3 is performing better for shorter deadlines but do not improve when superframe lengths are increased (fig. 6).

FAA 3 performs better with deadline of 30 ms for voice and video but for the longest deadline then FAA 1 and 2 are performing better as can be seen in Table III.

When the deadline is short for high utilization traffic, voice and video, then the major limiting factor when allocating nodes is the queueing deadline for this traffic. This queueing deadline (5) is decreased with the increasing number of nodes, since it depends on the duration of the control phase (9). When the control phase is increased the data phase is also decreased (1) leading to a lower amount of the radio resource being available for data transmission, however this impact is not decisive.

If different node types are separated onto different frequency channels, this leads to a fewer number of high utilization traffic nodes being allocated to frequency channels with a larger amount of data phase, i.e. utilizable radio resource. But of more importance is that the short queueing deadlines of the high utilization traffic have not been

decreased by accepting a large number of low utilization nodes to the same channel. This strategy is implemented by FAA 3; it utilizes a larger portion of the radio resource, for channels with mostly high utilization traffic nodes while not wasting their deadlines by separating different node types onto different channels. The downside is that large numbers of nodes with low utilization traffic are allocated to separate frequency channels where, due to a long control phase, a shorter queuing deadline is achieved. A limiting factor is then reached where nodes are rejected because delay requirements cannot be met, while there are available radio resources, i.e. low channel utilization is achieved. However, this is the strategy that allocates the nodes so that the largest average

Fig. 4 Different voice and video deadlines for FAA1

Fig. 5 Different voice and video deadlines for FAA2

Fig. 6 Different voice and video deadlines for FAA3

TABLE III. COMPARISON OF FAAS

FAA	T_{cycle} [ms]	Average number of nodes		Node type arrival [%]			
		Deadline for $h=2, h=3$		ρ_1	ρ_2	ρ_3	ρ_4
		$D_i=30$ ms	$D_i=200$ ms				
1	150	851	1107	1	9	9	81
2	150	851	1103	1	9	9	81
3	130	888	988	1	9	9	81

number of nodes is accepted, when high utilization traffic has short deadlines and for the specific node type arrival probability as presented.

When high utilization traffic have longer deadline, the radio resource can be better utilized by mixing different node types. We do not achieve as high individual channel utilization as when separating node types as far as possible, but also not as low average channel utilization. Instead since nodes types are mixed onto the frequency channels evenly the channel utilization have a higher average and is more even than when node types are separated. This strategy is implemented by FAA 1-2 and leads to a larger average number of nodes when the deadline for high utilization traffic is longer.

C. Comparison of FAA for different number of channels

Here the three FAAs are compared for a wider set of input parameters, when using the superframe lengths that were obtained in the previous subsection, with best performance. The algorithms are compared (fig.7) for different deadlines for voice and video and also for different number of frequency channels. The node type arrival probability ρ_k is preserved from the previous subsection.

Our proposed algorithm is performing better than the reference algorithms for shorter deadlines 30-50 ms when using several frequency channels. The performance for all FAAs is equal when using one frequency channel and the same superframe length. When the traffic deadline is larger or equal to 60 ms for voice and video then FAA 1 and 2 are performing better.

It can be concluded that when the traffic deadline for the high utilization traffic is increasing from 50-60 ms then the deadline for the high utilization traffic is no longer the major limiting factor. The high utilization traffic nodes are evenly allocated to different channels and their delay requirements are not jeopardized by adding larger number of low utilization nodes, instead this leads to a higher average utilization on every frequency channels, leading to a larger average number of accepted nodes.

D. Results for different fractions of node types

The results for different fractions of voice and video are presented for three cases for all FAAs. The first case is when only nodes without voice and video arrives (Table IV), second case is when all nodes arrive with equal probability $\rho_1 = \rho_2 = \rho_3 = \rho_4 = 25\%$ (Table V) and third case is when only nodes with both voice and video arrives (Table VI). The number of used frequency channels is 10.

FAA 3 performs equally well for case one and three but in case two where $\rho_1 = \rho_2 = \rho_3 = \rho_4 = 25\%$ then FAA 1 and 2 are performing slightly better.

E. Summary

The proposed algorithm and the two reference algorithms have different performance curves that complement each other to achieve a maximum number of accepted nodes, as we have

Fig. 7 Number of accepted nodes for selected superframes, FAA 1-3

TABLE IV. CASE ONE

FAA	T_{cycle} [ms]	Average number of nodes		Node type arrival [%]			
		Deadline for $h=2, h=3$		ρ_1	ρ_2	ρ_3	ρ_4
		$D_i=30\text{ ms}$	$D_i=200\text{ ms}$				
1	130	1650	1650	0	0	0	100
2	130	1650	1650	0	0	0	100
3	130	1650	1650	0	0	0	100

TABLE V. CASE TWO

FAA	T_{cycle} [ms]	Average number of nodes		Node type arrival [%]			
		Deadline for $h=2, h=3$		ρ_1	ρ_2	ρ_3	ρ_4
		$D_i=30\text{ ms}$	$D_i=200\text{ ms}$				
1	150	323	362	25	25	25	25
2	150	327	367	25	25	25	25
3	130	314	361	25	25	25	25

TABLE VI. CASE THREE

FAA	T_{cycle} [ms]	Average number of nodes		Node type arrival [%]			
		Deadline for $h=2, h=3$		ρ_1	ρ_2	ρ_3	ρ_4
		$D_i=30\text{ ms}$	$D_i=200\text{ ms}$				
1	150	180	200	100	0	0	0
2	150	180	200	100	0	0	0
3	150	180	200	100	0	0	0

found in our simulations, over the span of short and long deadlines for the high utilization part of the heterogeneous traffic. When the deadlines for these traffic classes are short it is advantageous to separate different node types onto separate frequency channels as far as possible. This is achieved with FAA 3. However when the deadlines are extended it is instead advantageous to mix different node types onto frequency channels since the deadlines for the high utilization traffic are not the major limiting factor any more. This is achieved with FAA 1 and 2.

These algorithms can be used together with a global algorithm that for different configurations finds the best schedule amongst FAA 1-3, in terms of maximum number of accepted mobile nodes. The search for the superframe lengths

that was made manually in subsection IV B can be included in the algorithms to be run at the system startup phase where extra delays can be tolerated. In a case where there is a new network configuration with new traffic requirements, then a search is made to find and save the well performing superframe lengths.

V. CONCLUSION

We have evaluated a proposed online heuristic based frequency allocation algorithm for a multichannel radio network and compared it to two well-known reference algorithms. The objective with the heuristic algorithms is to maximize the number of accepted single transceiver mobile nodes with heterogeneous traffic in the radio network. We used different mobile node types that have different fractions of the heterogeneous traffic. Different deadlines were used for voice and video traffic that have higher utilization than other traffic. When having longer deadlines for the high utilization traffic the reference algorithms were performing better than the proposed algorithm. However, in a more demanding requirement with shorter deadlines for the high utilization part of the traffic, then the proposed online algorithm performs better and supports a larger average number of nodes. It was found that for shorter deadlines for high utilization traffic it was more advantageous to separate different types of nodes onto separate frequency channels whilst for longer deadlines a mix of the node types onto the frequency channels showed better result in form of a larger number of accepted nodes. In our future work we will investigate other solutions to support a larger number of nodes with several base stations and possibly also looking outside the frame of deterministic solutions.

REFERENCES

- [1] H. Ramazanali, M. Jonsson, K. Kunert and U. Bilstrup, "Military training network with admission control using real-time analysis", 19th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2014 IEEE, Athen, Greece, Dec. 1-3, 2014, In press
- [2] H. Hoang and M. Jonsson, "Switched real-time Ethernet in industrial applications - deadline partitioning.", The 9th Asia-Pacific Conference on communications, APCC 2003, Penang, Malaysia, Vol.1, pp. 76-81, Sept. 21-24, 2003
- [3] C. L. Liu and J. W. Layland, "Scheduling algorithms for multiprogramming in a hard real time environment", Journal of the ACM, vol. 20, no. 1, pp. 46-61, 1973.
- [4] S. K. Baruah, A. K. Mok, and L. E. Rosier, "Preemptively scheduling hard-real-time sporadic tasks on one processor", Proc. 11th IEEE Real-Time Systems Symposium, RTSS 1990, pp. 182-190, 5-7 Dec. 1990.
- [5] S. K. Baruah, L. E. Rosier, and R. R. Howell, "Algorithms and complexity concerning the preemptive scheduling of periodic, real-time tasks on one processor", Real-Time Systems, Vol. 2, pp. 301-324, 1990.
- [6] M. Spuri, "Analysis of deadline schedule real-time systems", Technical Report 2772, Inria, France, 1996.
- [7] Saifullah, A.; You Xu; Chenyang Lu; Yixin Chen, "Real-time scheduling for wirelessHART networks" 31st IEEE Real-Time Systems Symposium (RTSS), pp.150-159, Nov. 30-Dec. 3, 2010.
- [8] Xiaorui Wang, Xiaodong Wang, Xing Fu, and Guoliang Xing. 2011. "MCRT: Multichannel real-time communications in wireless sensor networks", ACM Transactions on Sensor Networks, Vol. 8, No. 1, Article 2, 30 pages, Aug., 2011.
- [9] K-S. Shin, S-Y. Yun, D-H. Cho, "Multi-channel MAC protocol for QoS support in ad-hoc network", 8th Consumer Communications and Networking Conference (CCNC), 2011 IEEE , pp.975-976, 9-12 Jan., 2011.
- [10] P. Du, W. Jia, L. Huang, W. Lu, "Centralized scheduling and channel assignment in multi-channel single-transceiver WiMax mesh network", Wireless Communications and Networking Conference, IEEE WCNC 2007, pp.1734-1739, 11-15 March, 2007.