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Coexistence Plant Model for an Automated Coexistence Management

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Abstract: For data transmission of industrial applications parallel operations of various wireless communication systems are required in an industrial application environment. For guaranteeing that every application communication requirement of each wireless communication system is fulfilled, those systems have to be coexistent between each other. The process ensuring coexistence is called coexistence management process. In current approaches this holistic management is not considered yet. We want to develop an automated coexistence management with control engineering considerations. In this contribution we propose a basic model approach for a coexistence plant. For describing the structure and the time behaviour of a coexistence plant, Petri-net graphs are used. Therefore we split the state space into two description types. The first one describes the transfer of messages and the second one describes the time behaviour of state transition in the coexistence plant. Finally, the derived model on measurements in a 2.4 GHz frequency spectrum within a WiFi test environment is parametrised and validated.

Keywords: Communication control applications, Discrete event systems, Plants, Signal analysis, Wireless Communication systems

1. FIELD OF CONSIDERATION

There is no doubt that the use of wireless communication for industrial production and logistic processes will rapidly grow in the next few years. Due to diverse application communication requirements, different *wireless communication systems* (WCS) are going to be implemented in production facilities. These systems vary in technology (e.g. Bluetooth, WiFi, IEEE 802.15.4, DECT) and used frequency bands (e.g. 900 MHz, 1900 MHz, 2400 MHz, 5800 MHz). If WCS are using the same transmission medium, message transmission may be interfered. In detail, transmissions of different WCS interfere, when they take place in the *same time* domain, on the *same frequency* domain and at the *same location* domain. In Figure (Fig.) 1 we describe the interference of these three domains as an intersecting set.

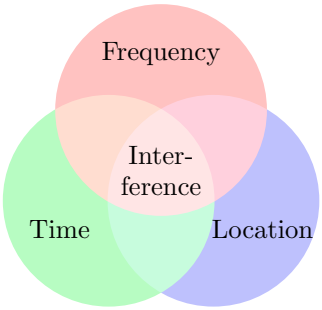

Fig. 1. Description of the intersecting set in time, frequency and location domain

If applications dispose of high requirements according to dependability and timeliness it is necessary to organise wireless communication to minimise interferences of wireless systems. Coexistence management is a measure to minimise the intersecting set as well as its influence to production processes. For the optimal development of appropriate coexistence management concepts and algorithms we developed an abstraction of the field of consideration for wireless coexistence management. In Fig. 2 key terms are introduced.

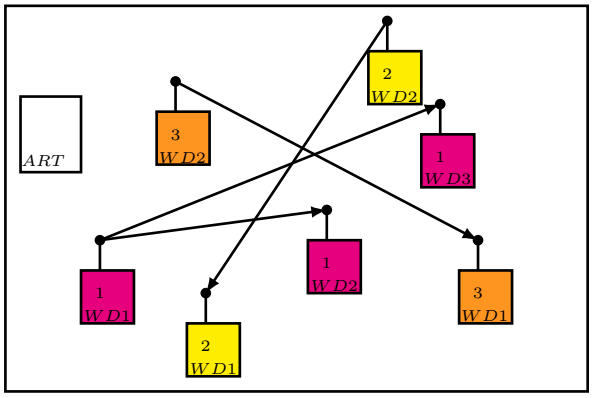

Fig. 2. Exemplary field of consideration

Three spatial *distributed automation applications* (DAA) are connected by WCS. Those WCS may be of different wireless technologies. They are subject of coexistence management. Outside of consideration there may be additional radio transmitters (ART). Those transmitters may influence the WCS and have, therefore, taken into

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account. However, they reside outside of the control of the coexistence management. A WCS consists of at least two *wireless devices* (WD). In Fig. 2 WD with the same number form one WCS. A WD can be *source* S (producer) or *target* T (consumer) of a message. This assigns its role in a logical link between two logical end points of an automation application. For message transmissions of a logical link, a physical link has to be established. In WCS physical links are implemented by radio channels. A radio channel is characterised by frequency, time and location. The set of all radio channels compose the transmission medium. If WCS operate independently, as usual today, the radio channels will most likely overlap and cause interferences. A holistic arrangement a so called wireless coexistence management is required.

2. COEXISTENCE MANAGEMENT APPROACHES

In [IEC62657-2 2014] wireless coexistence is defined as a "state in which all wireless communication systems of a plant using shared medium to fulfil all their application communication requirements". The process to ensure coexistence between wireless systems by planing, installing, commissioning, operating, and maintaining WCS is called *coexistence management process*.

Medium control access mechanisms have been developed to separate radio channels within WCS to minimise interferences. This is done by assigning different use of frequency or time to radio channels. The location aspect is considered implicitly by assessing the received power. However, this may lead to problems. The transmitter of a physical link does not receive the same power level of an interferer as the intended receiver of the physical link due to radio propagation conditions. This may lead to transmissions that will be interfered or it may prevent transmissions that would not be interfered. Both results degrade the efficient use of the spectrum. Thus, medium control access mechanisms are not sufficient to ensure coexistence in wireless industrial automation. They do not consider application and system aspects. These aspects, however, are essential according to the definition of coexistence. Furthermore, those mechanisms do not sufficiently take into account the radio propagation conditions, also called passive environmental conditions.

Investigations on wireless coexistence and its management have already been done years ago [LaSorte et al. 2012], [Gnad et al. 2008], [Kraetzig and Rauchhaupt 2008]. The results have been considered in international standardisation [IEC62657-2 2014]. The intention is to reach or rather to maintain the coexistence of different WCS. In Fig. 3 we give an overview over different implementations of coexistence management approaches. There are four types of coexistence management implementation: manual management, automated cooperated management, either centralised or decentralised, and automated non-cooperated management.

In case of manual management a person is responsible for preventing disturbances of the wireless applications. The only degrees of freedom a human coexistence manager has is to change the frequency channel and to limit the extent of the location of wireless communication devices. If the device positions are determined by the application the only

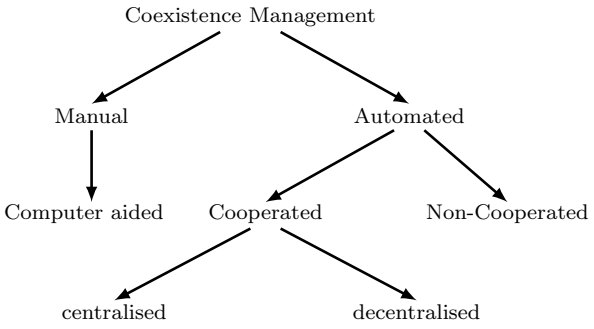

Fig. 3. Overview of coexistence management implementations

measure for coexistence management is the assignment of different frequency channels to different WCS. However, this method is not flexible because it needs some time to analyse the frequency spectrum usage and the possibilities to rearrange the spectrum according to the changed requirements. Furthermore, it wastes resources since the frequency spectrum is blocked, independent of the time it is used. Therefore, manual coexistence management is only advisable as far as no more advanced measures are available. The following methods of considerations refer to automated coexistence management processes.

An automated non-cooperative management means that different WCS cannot exchange information between each other about their state. Every WCS has its own medium access mechanism. As a result they just react on disturbances and adapt their own behaviour on the current state. That means a non-cooperative management system is prone to disturbances due to different WCS. Devices from these different WCS make decisions regarding their own medium access. This could be *frequency hopping* or *listen before talk* (LBT). The first method is e.g. used in IEEE 802.15.1, on which Bluetooth is based. The second one is e.g. used in IEEE 802.11., defining WiFi. In this context the automated management refers to the device. For the system as a whole an automated non-cooperated management is missing. In literature there are only segments, which can be used for an automated coexistence management, such as cognitive medium access. In [Geierhofer et al. 2008], a continuous-time Markov chain model is used to capture the WiFi medium access for prediction. The model is relaxed into a constrained Markov decision process, formulating the problem with linear programming. This algorithm depends on WiFi technology. However for a holistic coexistence management approach several wireless technologies have to be taken into account. Further information about approaches in cognitive radio can be found in [Haykin 2005], [Ahmad et al. 2012], [Ahmad et al. 2011], [Yuecek and Arslan 2009] and the references therein. In [Schimschar and Kraetzig 2012] a model approach for simulating wireless coexistence scenarios is presented, based on hierarchical and timed coloured Petri-nets. For coexistence management this approach is not generic enough for implementing controller based approaches. However, fundamental results of this work will be considered.

The last type of coexistence management is an automated cooperated one. That means that wireless communication