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MULTI CRITERIA EVALUATION OF WIRELESS LOCAL AREA NETWORK DESIGNS

Summary. The paper presents proposal of multi criteria evaluation method of Wireless Local Area Network designs. It is based on a simple model of WLAN network along with its quality indices proposal. Next meta-criterion functions are presented. Finally simulation results run in MATLAB environment are presented.

Keywords: computer network design, wireless local area network, multi criteria decision making

WIELOKRYTERIALNA OCENA PROJEKTÓW BEZPRZEWODOWYCH LOKALNYCH SIECI KOMPUTEROWYCH

Streszczenie. Artykuł przedstawia propozycję metody wielokryterialnej oceny projektów lokalnych sieci bezprzewodowych (WLAN). Bazuje ona na prostym modelu sieci WLAN wraz z propozycją jej wskaźników jakości. Następnie przedstawione są funkcje metakryterialne oraz wyniki badań symulacyjnych w środowisku MATLAB.

Słowa kluczowe: projektowanie sieci komputerowych, lokalne sieci bezprzewodowe, wielokryterialne podejmowanie decyzji

1. Introduction

The goal of local area networks design is to find suitable sets of network parameters which fulfil future user's needs and requirements. In the case of wireless networks some parameters of workstations (wireless adapters), access points and antennas are chosen.

The paper presents application of the method in the field of WLAN design. Three quality indices of WLAN network are chosen: maximum coverage, total cost and reliability of the network. The application of the method in the process of evaluation of the WLAN networks is simulated in MATLAB environment.

2. Wireless Local Area Network Model

Wireless Local Area Networks (WLANs) are built of two types of network devices: wireless network adapters attached to workstations (network nodes) and access points that are in the centre of a wireless cell. Additionally, access points can be equipped with external antennas that allow increasing coverage of the network cell. For the purposes of this model it is assumed that the network consists of N network nodes (*NN*), one central access point (*AP*) and antenna (*AN*) that can be attached to *AP*.

2.1. Parameters of Network Equipment

WLAN composed of *NN*, *AP* and *AN* is characterized by their parameters, which influence the performance – quality indices. Set of parameters of network equipment is presented in Table 1.

Table 1

Parameters of WLAN equipment

parameter	*description*	*type*	*unit*
P_1^{NN}	*NN* – price	continuous	USD
P_2^{NN}	*NN* – brand	continuous	$P_2^{NN} \in [0 \dots 1]$
P_3^{NN}	*NN* – TX max power	continuous	dBm
P_4^{NN}	*NN* – RX min sensitivity	continuous	dBm
P_1^{AP}	*AP* – price	continuous	USD
P_2^{AP}	*AP* – brand	continuous	$P_2^{AP} \in [0 \dots 1]$
P_3^{AP}	*AP* – TX max power	continuous	dBm
P_4^{AP}	*AP* – RX min sensitivity	continuous	dBm
P_1^{AN}	*AN* – price	continuous	USD
P_2^{AN}	*AN* – brand	continuous	$P_2^{AN} \in [0 \dots 1]$
P_3^{AN}	*AN* – gain	continuous	dBi

2.2. Quality Indices of WLAN Model

There are given three quality indices for presented WLAN model: maximum coverage of WLAN cell, total cost of WLAN set-up and reliability of WLAN.

- Maximum coverage of WLAN cell – q_1 :

$$q_1 = f_1(P_3^{NN}, P_3^{AP}, P_3^{AP}, P_4^{AP}, P_3^{AP}, \Delta P) \quad [m],$$

$$q_1 = min\left(\frac{10^{\frac{P_3^{AP} - P_4^{NN} + P_3^{AP} - \Delta P - a}{20}}}{b}, \frac{10^{\frac{P_3^{NN} - P_4^{AP} + P_3^{AP} - \Delta P - a}{20}}}{b} \right), \tag{1}$$

where a = 104 and $b = 6.21 \cdot 10^{-4}$.

- Total cost of WLAN set-up – q_2 :

$$q_2 = f_2(P_1^{NN}, P_1^{AP}, P_1^{AN}) \quad [USD],$$

$$q_2 = N \cdot P_1^{NN} + P_1^{AP} + P_1^{AN} . \tag{2}$$

- Reliability of WLAN – q_3 :

$$q_3 = f_3(P_2^{NN}, P_2^{AP}, P_2^{AN}) \quad [0 \ldots 1],$$

$$q_3 = \frac{1}{2}\left[\frac{1}{3}\left(P_2^{NN} + P_2^{AP} + P_2^{AN}\right) + q_{3_p}\right], \tag{3}$$

where:

- $q_{3_p} = 0$ if $BM_{q_3} - \Delta P \leqslant 0$ or $q_{3_p} = 1$ if $BM_{q_3} - \Delta P > 0$,
- $BM_{q_3} = min\left(BM_{AB}(l = l_{min}), BM_{BA}(l = l_{min})\right)$,
- $BM_{AB}(l = l_{min}) = P_3^{AP} - P_4^{NN} + P_3^{AN} - T_{AB}(l = l_{min})$,
- $T_{AB}(l = l_{min}) = T_{BA}(l = l_{min}) = a + 20 \cdot \log_{10}(b \cdot l_{min})$.

The results given by q_1 and q_2 indices are in physical units (meters and USD, respectively) but q_3 index gives result as number in the range [0...1]. In order to be able to build one metacriterion it is necessary to normalize q_1 and q_2 indices, which is achieved through the following operations:

$$q_{1N} = \frac{q_1 - q_{1min}}{q_{1max} - q_{1min}} \quad \text{and} \quad q_{2N} = \frac{q_2 - q_{2min}}{q_{2max} - q_{2min}} ,$$

where q_{1max} , q_{2max} and q_{1min} , q_{2min} are given maximal and minimal values of respective quality indices.

2.3. Meta-Criterion

There are many ways of building meta-criterion based on dependent criteria known in multi-criteria decision analysis area [1]. General form of meta-criterion used here is a power function:

$$Q_\gamma(q)=\left[\sum_{n=1}^{N} w_n \cdot q_n^\gamma\right]^{1/\gamma}, \quad (4)$$

where $\gamma \geq 1$ is a parameter, w_n is n-th weight, q_n is n-th quality index and $w_n >= 0$, $\Sigma_n w_n = 1$.

For $\gamma = 1$ we get the linear form known as *weighted sum*:

$$Q_1(q)=\sum_{n=1}^{N} w_n \cdot q_n, \quad (5)$$

and for $\gamma = 2$ we get square root form:

$$Q_2(q)=\sqrt[2]{\sum_{n=1}^{N} w_n \cdot q_n^2}. \quad (6)$$

The Q_2 has advantage over Q_1 taking into account differences among quality indices. In extreme case:

$$\lim_{\gamma \to +\infty} Q_\gamma(q)=max \quad q_n, \quad (7)$$

so the value of Q_γ is for $\gamma \to +\infty$ the highest value of the indices, and it is not always advantageous.

The Q_1 function has been previously used for wire local area networks designs evaluation [2]. In both cases of Q_1 and Q_2 their maximization is desired.

3. Simulation Results

Above-described WLAN model along with its parameters, quality indices and meta-criterion has been applied as part of the computer aided network design process. The simulation has been run in MATLAB environment.

3.1. Experiment 1 – Predefined Model Parameters

Following input data has been used in the experiment: $N = 6$ (number of network nodes), $\Delta P = 5$dB (power margin), $l_{min} = 50$m (minimal radius of wireless cell), $q_{1min} = l_{min}$, $q_{1max} = 12000$m, $q_{2min} = 0$USD, $q_{2max} = 1500$USD. Both Q_1 and Q_2 functions have been applied with weights $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.1$ and samples from result matrix are presented in Table 2.

Table 2
Sample values of normalized quality indices and meta-criteria for selected NN, AP and AN combinations

NN	*AP*	*AN*	q_{1N}	q_{2N}	q_{3N}	Q_1	Q_2
6	2	2	0.4052	0.8113	0.9333	0.6326	0.6736
2	1	2	0.2541	0.8270	0.9667	0.5685	0.6514
6	2	1	0.2856	0.8121	0.9333	0.5731	0.6426
3	3	1	0.2856	0.7821	0.9167	0.5608	0.6264
7	1	4	0.2010	0.7154	0.9500	0.5051	0.5952
7	3	5	0.2541	0.6738	0.8333	0.4959	0.5544
8	3	1	0.1588	0.7981	0.8333	0.4855	0.5853
9	1	5	0.0875	0.8355	0.8000	0.4544	0.5841

3.2. Experiment 2 – Change of Network Node Number *N*

Following input data has been used in the experiment: $\Delta P = 5$dB (power margin), $l_{min} = 50$m (minimal radius of wireless cell), $q_{1min} = l_{min}$, $q_{1max} = 12000$m, $q_{2min} = 0$USD, $q_{2max} = 1500$USD. Both Q_1 and Q_2 functions have been applied with weights $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.1$. The result is shown in Figure 1. It shows Q_1 and Q_2 in function of N.

With increasing of network size (number of network nodes – N parameter) the value of both Q_1 and Q_2 is decreasing.

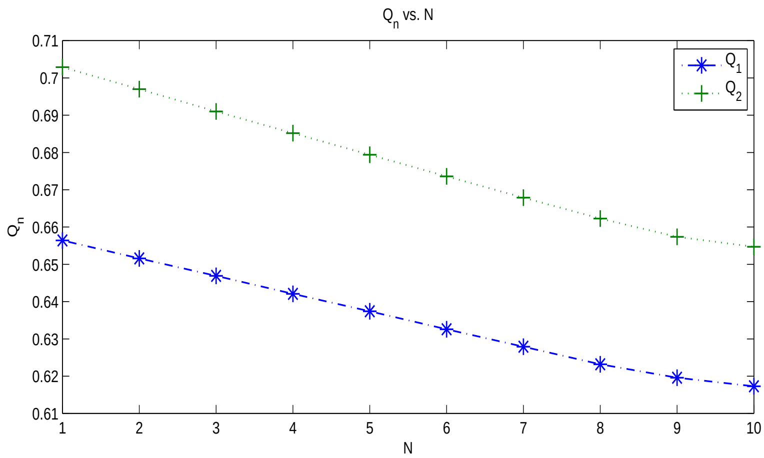

Fig. 1. The Q_1 and Q_2 in function of N
Rys. 1. Q_1 oraz Q_2 w funkcji N

3.3. Experiment 3 – Change of Power Margin Δ*P*

Following input data has been used in the experiment: $N = 6$ (number of network nodes), $l_{min} = 50$m (minimal radius of wireless cell), $q_{1min} = l_{min}$, $q_{1max} = 12000$m, $q_{2min} = 0$USD, $q_{2max} = 1500$USD. Both Q_1 and Q_2 functions have been applied with weights $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.1$. The result is shown in Figure 2. It shows Q_1 and Q_2 in function of ΔP. Increasing ΔP influence q_{1N} quality index and yields decreasing of both Q_1 and Q_2 values for specified set of weights. However, for the values of $\Delta P \in [7...14]$, Q_2 function values are changing very slightly.

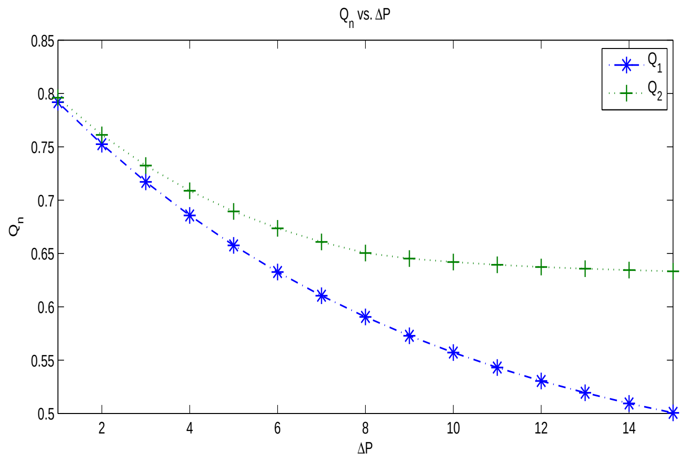

Fig. 2. The Q_1 and Q_2 in function of ΔP
Rys. 2. Q_1 oraz Q_2 w funkcji ΔP

3.4. Experiment 4 – Change of Minimal Radius of Wireless Cell l_{min}

Following input data has been used in the experiment: $N = 6$ (number of network nodes), $\Delta P = 5$dB (power margin), $q_{1min} = l_{min}$, $q_{1max} = 12000$m, $q_{2min} = 0$USD, $q_{2max} = 1500$USD. Both Q_1 and Q_2 functions have been applied with weights $w_1 = 0.5$, $w_2 = 0.3$, $w_3 = 0.1$ and samples from result matrix are presented in Figure 3. It shows Q_1 and Q_2 in function of l_{min}. Increasing l_{min} requirement has very small influence meta-criterion value.

3.5. Discussion on Results

Applying model of WLAN quality indices in presented method allows for integrating three quality indices with weights chosen by designer of the network in one meta-criterion. The possibility has been shown for selected input data. It is easy to notice explicit influence of weights on the values of Q function.

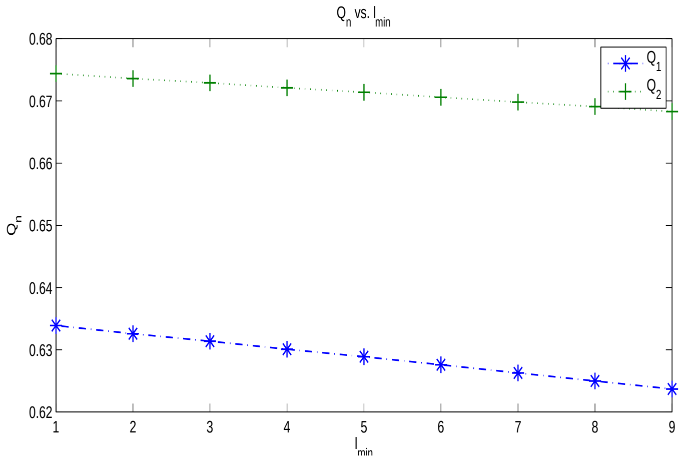

Fig. 3. The Q_1 and Q_2 in function of l_{min}
Rys. 3. Q_1 oraz Q_2 w funkcji l_{min}

4. Conclusion

The paper presents the problem of Wireless Local Area Network design and proposal of multi-criteria evaluation method of such designs. The method is based on three so-called quality indices – maximum coverage of the cell, total cost of network set-up and reliability of the network. These quality indices are integrated in one meta-criterion, for which two functions have been proposed. Finally some simulation results obtained in Matlab environment have been show. It has been shown that such method of multi criteria evaluation of WLAN designs is usable in the process of WLAN design. It is however quite different from previously used WSM and WPM methods [2] or AHP method [3].

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Omówienie

Artykuł prezentuje propozycję metody wielokryterialnej oceny projektów bezprzewodowych lokalnych sieci komputerowych. Bazuje ona na prostym modelu sieci WLAN, opartym na założeniu funkcjonowania w architekturze z jednym centralnym punktem dostępowym (*AP*) oraz *N* stacjami roboczymi (*NN*); ponadto możliwe jest dołączenie anteny (*AN*) do *AP* celem zwiększenia zasięgu komórki dostępowej. Parametry elementów sieci scharakteryzowane są wybranymi parametrami (tab. 1), które mają wpływ na trzy zaproponowane wskaźniki jakości – maksymalny zasięg komórki dostępowej q_1 (równanie 1), koszt budowy sieci q_2 (równanie 2) oraz niezawodność sieci q_3 (równanie 3). Wskaźniki te są następnie zagregowane w jedno metakryterium jakościowe, opisywane dwiema zależnościami funkcyjnymi Q_1 oraz Q_2 (równania: 5 i 6). Rozdział 3 prezentuje badania eksperymentalne przeprowadzone w środowisku MATLAB. Dla wybranych wartości parametrów przedstawiono przykładowe wartości znormalizowanych wskaźników jakości oraz metakryteriów jakościowych Q_1 oraz Q_2 (tab. 2). Kolejno przedstawione są wartości Q_1 oraz Q_2 w zależności od: zmian liczby węzłów sieci *N* (rys. 1), zapasu mocy ΔP (rys. 2) oraz minimalnego promienia komórki dostępowej l_{min} (rys. 3). Można zauważyć ponadto wyraźny wpływ doboru wag na wartość funkcji metakryterium jakościowego. Podsumowując, zauważyć należy, iż przedstawiona metoda użyteczna jest w procesie oceny projektów sieci WLAN, jakkolwiek czyni to w sposób inny od dotychczas używanych metod WSM i WPM [2] czy AHP [3].

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