

## Research Article

### A Network Selection Indicator Based on Golden Relation between Monetary Cost and Bandwidth in Heterogeneous Wireless Networks

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**Abstract:** The selection of an optimal access network is an essential aspect of service delivery in heterogeneous wireless networks. Many efficient methods are used in the selection of the best network. The relation between monetary cost and bandwidth affects the network selection process, but this consideration is not accounted for in other selection processes. This study proposes the use of golden ratio to determine the mathematical relation between monetary cost and bandwidth, which can serve as a viable indicator for both users and service providers. Results and analyses illustrate the efficiency of the suggested relation to select the best network in heterogeneous wireless networks and optimize user and network provider satisfaction levels.

**Keywords:** Golden ratio, heterogeneous wireless networks, network selection, relation between cost and bandwidth

## INTRODUCTION

Various technologies applied by one or more operators have to be integrated in Next-Generation Wireless Networks (NGWNs) to form a heterogeneous environment based on an Internet Protocol (IP) core network infrastructure. Such environment guarantees user mobility and service continuity by sustaining the connections when switching between various technologies. It also introduces new resources and possibilities for applications (Kassar *et al.*, 2008). However, a single technology can hardly satisfy all of the application's expectations. Therefore, the integration of different wireless technologies in a heterogeneous environment can improve the delivery of these applications. However, in several situations, a Mobile Node (MN) tends to connect with high-performing networks to maintain the expected connection, which overloads the best-performing technology while underutilizing the other technologies. An automatic interface selection is adopted to overcome this problem and to benefit from technology diversity, while considering its immediate and real constraints as well as user preferences. Constraints in operator and network resources management have become inevitable as well.

The Network Selection (NS) process in such setting is affected by a number of factors and a solution for this issue has not been discovered. Selection of the best network depends on various parameters that affect

the Vertical Hand Over (VHO) decision process. These parameters include monetary cost, Band Width (BW), Quality of Service (QoS) and service type (Wang and Kuo, 2013). NS complexity is considered a decision problem (Trestian *et al.*, 2012). Choosing a network that meets all of the users' criteria may be difficult, because some of these criteria are contradictory. Each user has a unique set of preferences. One user may prefer the cheapest network, whereas another user may prefer a high-bandwidth connection. A practical relation exists among the most effective parameters in VHO selection, such as monetary cost and BW. When network providers increase the BW, the price is also increased. The promotion of such increase differs among companies of the same or various technologies. Determining the relation between cost and BW can solve the underlying complexities in a multiple-criteria decision-making process.

Many works have discussed the NS problem in Heterogeneous Wireless Networks (HWNs) and many effective mechanisms have been used to address this problem, such as Multiple Attribute Decision Making (MADM) (Salih *et al.*, 2012), fuzzy logic (Kaleem *et al.*, 2013), MARKOV (Wang *et al.*, 2008), game theory (Niyato and Hossain, 2009) and utility theory (Ormond *et al.*, 2006). The NS process considers many parameters, such as monetary cost, BW, delay, packet loss, jitter, throughput and service type. The abovementioned methods address the NS process without considering the relation between parameters.

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The current study determines a significant mathematical relationship between monetary cost (price) and BW, which can serve as a basis for a new method for MNs to select the best network within a specified BW and monetary cost.

This study investigates the relation between the certainty of BW and certainty of monetary cost. The golden ratio is found to be a viable method for the detection of a relation between the said parameters. We propose a new mathematical relation between monetary cost and BW. Our proposed method can guide both users and service providers in determining the best relation between cost and BW. We have also observed that natural phenomena are fundamental in solving the NS problem.

## METHODOLOGY

**Principles and definitions:** The importance of monetary cost and BW in the NS process is discussed first. Other studies have cited monetary cost, BW, QoS and service types as effective parameters in the NS process. QoS parameters, such as delay, packet loss and jitter, are important in the handover process. However, many of these QoS parameters cannot be controlled by telecommunication service providers because they may be caused by external factors. For example, delay and packet loss can be caused by the weather or a user's location. Service type can also be used for making decisions in the handover process. Most technologies such as LTE, UMTS, WiMAX and Wi-Fi support most of the service types, but with different quality levels that are determined by the BW. An increase in BW also increases the QoS and the cost. Some users try to find a cheap technology with a higher BW, while the service providers try to provide higher BW with a fixed, highly profitable cost. The users can connect to multiple wireless networks in heterogeneous wireless environment. They usually prefer the network with the highest BW and lowest cost. The service providers try to provide their best offers to satisfy their users. Monetary cost and BW are the most effective parameters in the VHO decision process (Tawil *et al.*, 2008). These parameters may be controlled by the service provider. Service providers can promote MN by increasing the BW per cost or by decreasing the cost per BW. The focus of this research is to find a mathematical relationship between these two parameters, such that the MN can select the network that has a certain BW and a certain cost. Figure 1 explains the relation between cost and BW.

The pricing of different services and technologies has become a crucial matter given the commercialization of the services that follow the NS process. Economists and technologists are unsure of the need for the creation and execution of new pricing strategies. These strategies need to be investigated further. This section describes three pricing strategies, namely, flat-rate, capacity-based and usage-sensitive pricing schemes (Bailey *et al.*, 1998). These pricing



Fig. 1: Relation between cost and BW

strategies co-occur within and across market segments and can be expected to co-occur in forthcoming services infrastructure (Bailey *et al.*, 1998).

The most commonly used pricing strategy, particularly in the current Internet service, is flat-rate pricing, in which users pay a fixed monthly subscription fee instead of paying for the total amount of transmitted data. This fee is fixed regardless of the speed or configuration of the connection. One merit of this pricing is that its fee is easily set for services, which enables the users to manage their budget easily. Capacity-based pricing links pricing to usage by determining the price based on BW or speed of the connection. This pricing strategy depends on the estimated usage of a circuit as no accounting is performed on the link. Estimation can be performed by charging for the configuration (i.e., BW) of the link, because this factor is correlated to the actual bits that are sent and/or received.

Capacity-based pricing is different from usage-sensitive pricing because the latter charges for the actual usage and not for the probable usage. This difference is significant because usage-sensitive pricing entails accounting in addition to billing, whereas capacity-based pricing entails billing for cost recovery only. The method of accounting for usage-sensitive pricing determines the price and the inducements for network users and providers. This strategy provides network providers with more elasticity when designing their pricing model. Pricing during the daytime and organizing the precedence of circulation enable network providers to decrease crowding on their network by modeling the behaviors of their users, which is basically a process of load administration. Both cost and BW are vital policy objectives. The certainty of BW is essential for services to function as a platform for advanced communication, information and entertainment services, or even telephony. The certainty of price is important for universal service.

### Golden ratio:

**Origins of the golden ratio:** This inquisitive mathematical relation has been revealed more than 2,000 years ago in Euclid's Elements, Book VI, Proposition 30 (Falbo, 2005). The golden proportion or golden ratio is denoted by the Greek letter Phi ( $\phi$ ), which represents an approximately irrational number,

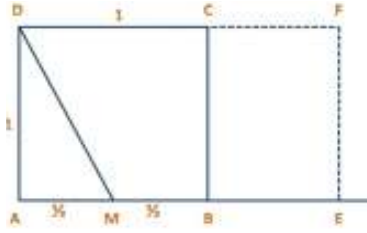


Fig. 2: Euclid's idea of the golden ratio

1.6180339887. Figure 2 shows Euclid's initial idea. The problem can be specified as follows:

Given a segment AE, point B for which  $AE/AB = AB/BE$  is identified. If  $AE = AB + BE$ , or  $AE = 1 + BE$ , then  $AE = (1 + \sqrt{5})/2$ . Thus,  $AE/AB = AB/BE$ . The length AE,  $(1 + \sqrt{5})/2$  is denoted by  $\phi$  and is called the golden ratio. The rectangle AEFD in Fig. 2 is called a golden rectangle.

Although it has been used for more than 2,000 years, the golden ratio is currently being targeted for re-investigations and re-analyses to prove its benefit. Otherwise, the golden ratio may merely be considered as a certain ratio.

**Concept of ideal proportions in the golden ratio:**

Many researchers and mathematicians have explored the golden ratio because of its distinctive and

mysterious features. Renaissance architects, artists and designers have also allotted some of their research efforts to investigate this exciting area. They have utilized the golden ratio in their creation of artifacts, sculptures, paintings and architectures (Akhtaruzzaman and Shafie, 2012). The golden ratio is regarded as the most alluring to the human visual sensation. It is not restricted to artistic beauty, but has also found its position in the real world through the body parts of living beings, the growth forms of many plants and insects and also in the formation of a perplexing universe. The idea that the Egyptians employed the golden ratio in their construction of huge pyramids and the belief that the Greeks used this same ratio in designing the entire interior of the Parthenon explain the amazement of mankind with these structures. Figure 3 shows examples in which the golden ratio is found pleasing to human visual sensation and existence in the natural world. It is very distinctive in its mathematical assets and universal in its form through nature. Its natural proportioning system has supported many works (Nikolic and Cosic, 2011).

This study seeks to solve the multi-objective selection problem in heterogeneous wireless communication networks by using the golden ratio to find the relation between cost and BW. This relation

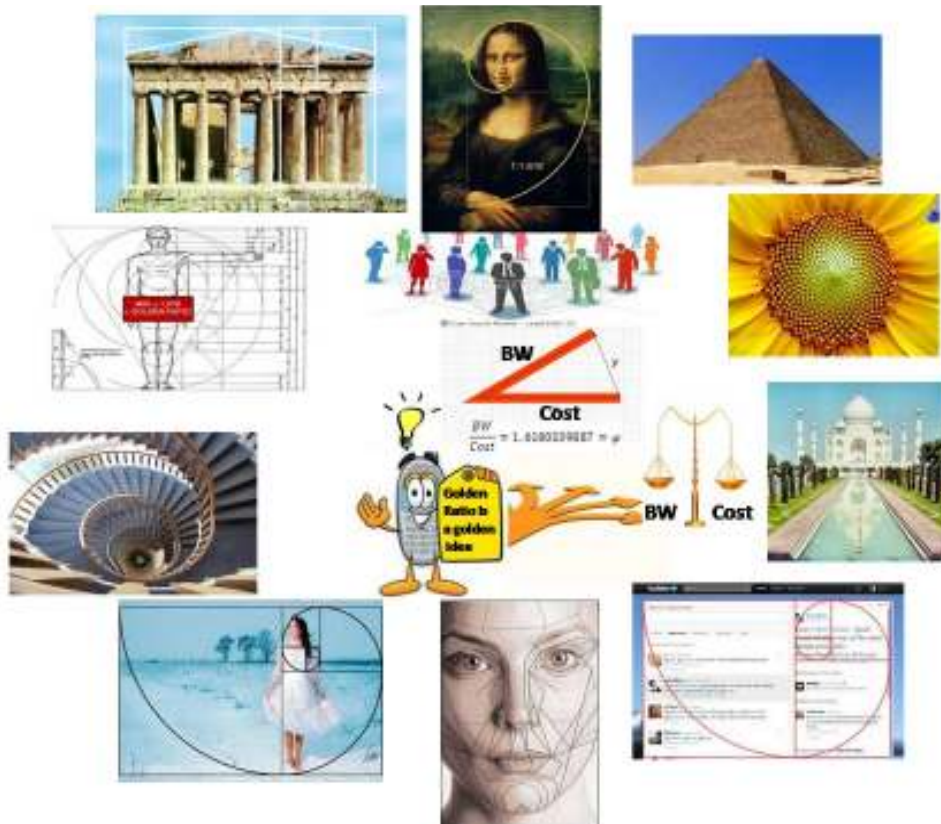


Fig. 3: Usage of golden ratio in human's visual sensation and existence in the natural world

plays an important role in selecting the best network among different available wireless networks.

**Golden ratio's formulation of the relation between the cost and bandwidth:** Mathematically challenged individuals perhaps wonder about the appearances of  $\phi$  in heterogeneous wireless communication networks. The golden section refers to the point in a line segment in which the line is classified into two sections with unique properties, such as the ratio between the bigger and shorter segments having to equal the ratio between the line and its bigger segment (Falbo, 2005). The ratio is approximately 1.6180339887 and is denoted by the Greek letter  $\phi$ . If a line AC is considered according to Fig. 4, point B is considered as its golden section where the line is divided into two sections, namely, cost (C) and Band Width (BW), where (AB = C and BC = BW). In accordance with the theory, the ratio of C and BW is equal to the ratio between (C + BW) and C, where C > BW. This relation is further explained by the equation:

$$\phi = \frac{C}{BW} = \frac{(C+BW)}{C} = \frac{1+\sqrt{5}}{2} = 1.6180339887 \text{ (approx.)} \quad (1)$$

By regarding any of the two segments of line AC as equal to 1, the other segment may be obtained based on the value of  $\phi$ . If BW is regarded as 1 (BW = 1), then C is considered to have the value  $\phi$  (C =  $\phi$ ). If C is regarded as 1 (C = 1), then the value of BW is the reverse of  $\phi$  (BW =  $1/\phi$ ). The golden section is the most aesthetically pleasing point where the line is divided. This notion has been accordingly assimilated in this study to select the best HWNs based on the usage of other sciences such as artworks, architectural designs and mathematical analyses.



Fig. 4: A line segment AC is divided in the golden section point B

The relation between cost and BW can be formulated by the golden ratio, whereas the exponential function is computed by dividing the gradually increasing cost with the sampling interval as shown in Eq. (2):

$$BW = e^{(C/\phi)/60} \quad (2)$$

where,  
 BW = The bandwidth  
 C = The cost  
 60 = The sampling interval  
 $\phi$  = The golden ratio

### PERFORMANCE EVALUATION

Equation (2) shows that the golden ratio can be used to formulate the relation between cost and BW. The exponential function describes a relationship in which a fixed gradual change steadily establishes the relation between cost and BW, which gives the same relative change (i.e., percentage increase or decrease). Figure 5 shows that the BW graph slopes upward and increases faster compared with the increase in cost.

Given the existence of many service providers who provide different wireless network technologies, policy makers of these service providers must focus on improving their competitive edge by providing their users with higher BW for a lower price. On the network providers' side, a policy (certain ratio) that can satisfy

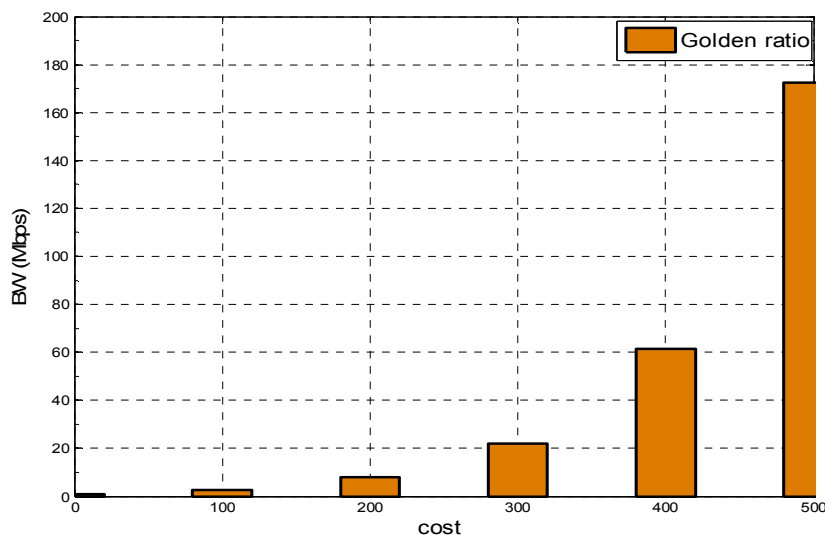


Fig. 5: Golden ratio formulation

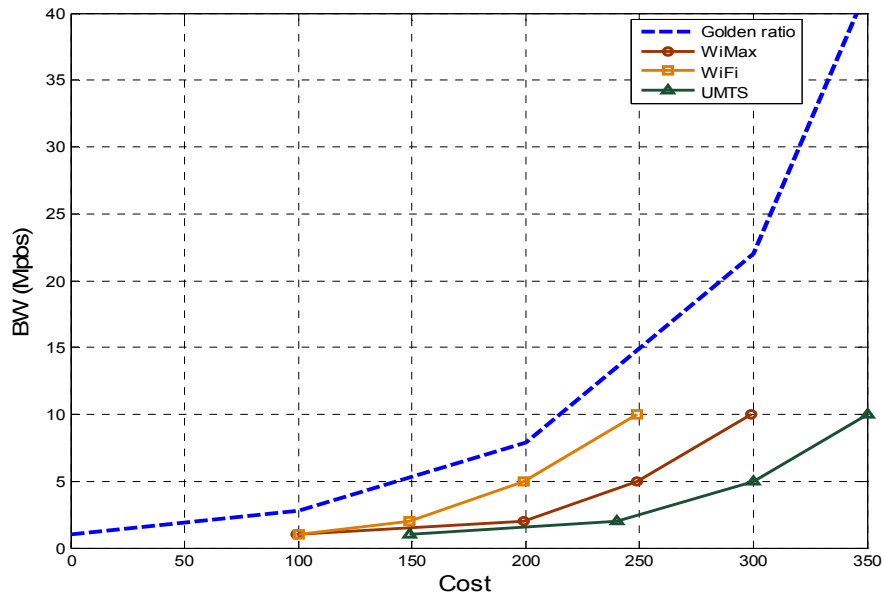


Fig. 6: Comparison of the three technologies with the golden ratio

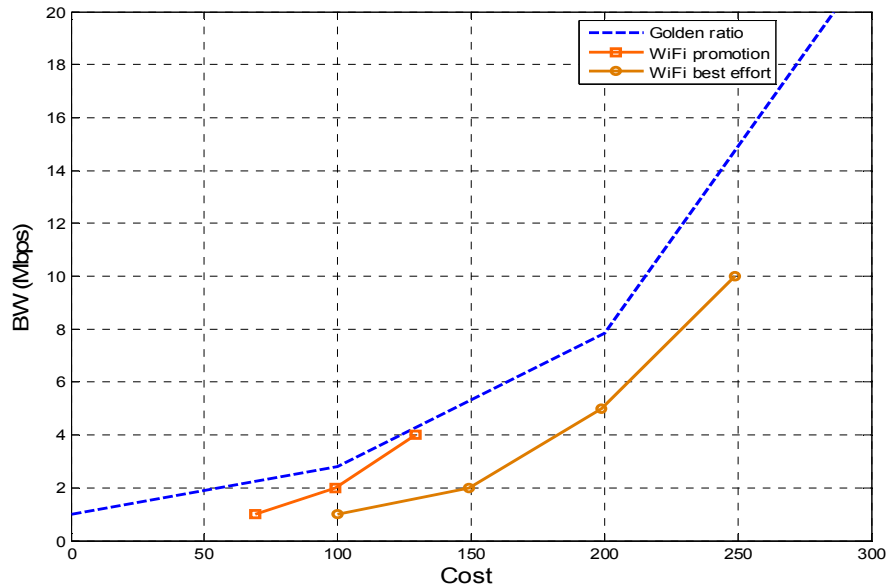


Fig. 7: Comparison of the best effort and promotion with the golden ratio

the users and bring large profits to the company needs to be strategized. On the users' side, they have to look for a technology that can provide them with higher BW for a lower cost. Figure 6 compares three types of local technologies, namely, Wi-Fi, WiMAX and UMTS, with this study's proposed relation. We used flat-rate pricing (Malaysian currency) for internet service. Based on the results, the golden ratio provides the ideal solution to determine the relation between the cost and BW. The three technologies attempt to reach the golden ratio. Thus, the golden ratio can be used by both users (with different preferences) and technologies (from different companies with different plans) to identify a satisfactory

relation between the cost and BW. Moreover, the golden ratio can unify the viewpoints of both users and network providers. Figure 6 shows that the relationship between the cost and BW in Wi-Fi is the closest to the golden ratio compared with other technologies. The relation between cost and BW in UMTS seems reasonable because it has a higher service cost compared with the other technologies. A better technology has a cost-bandwidth relationship that is closer to the golden ratio.

Users look for a method to determine whether the services of certain network service providers are satisfactory or not. Some service providers send

messages to users claiming that they have cost-effective offers, but users find better offers from other service providers after making comparisons. This phenomenon is because network providers have their own policies, whereas users do not follow any policies. No standard policies exist for both users and service providers. Thus, a global policy among service providers themselves and between service providers and users, must be established. The golden ratio can also be used to formulate standard policies by finding an ideal relation between a certain BW and a certain cost that can satisfy both service providers and users. Figure 7 shows that Wi-Fi nearly satisfies users by offering a promotion, with relation between cost and BW that has been tested by users using the golden ratio. The promotion has also been compared with the Wi-Fi's best effort service. The Wi-Fi promotion reached the golden ratio, especially with an increased BW. Thus, users can utilize the golden ratio to determine the best offers (best effort or promotion) of different technologies for the selection of best networks in heterogeneous wireless environments.

The results prove that the golden ratio can serve as a guide for both users and network providers in finding the best relation between cost and BW. The mathematical formulation of a natural phenomenon is fundamental in solving the multi-objective NS problem. The results show that the golden ratio can be a good indicator better than using utility theory (Salih and Ong, 2013) to measure the user's satisfaction.

### CONCLUSION

We have proposed a golden mathematical relation between monetary cost and BW by using the golden ratio. This relation can guide both users and service providers in finding the best relation between the two important selection factors. This relation is used as an indicator to select the best network in heterogeneous wireless environments. The results and analysis have proved our idea that finding a golden relation between cost and BW to determine the best network can satisfy both users and network providers. The research has shown that the golden ratio generally affects users' preferences and service providers' offers.

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