Handover between Vehicular Network Providers Using Bioinspired Attractor Selection Technique

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1. Introduction

While vehicles are still required to transport drivers and passengers to their destinations, other aspects of driving are rapidly evolving around the globe. Reliable and consistent connectivity is driving this trend. As consumers expect better connected-vehicle experiences, automakers are adopting connectivity standards and advanced driving requirements.

Many responses to the vehicular dynamic environment are presented in research and technical publications. Connected vehicles have long been considered as the next generation in the automotive industry, as the Internet of Things (IoT) and Internet of Vehicles (IoV) continue to grow at a rapid pace. The ability of a vehicle to connect to the home, other vehicles, and roadside equipment will affect travel behavior and the way the automotive business interacts with customers [1–5].
high-speed network infrastructure with the best security, dependability, high-speed data transfer, and ultralow latency is required. Adaptive approaches address critical concerns like traffic volumes, safety, congestion, connection, big data, and scalability as a result of network development. This is due to the nonlinear dynamic nature of traffic, which is growing in demand and necessitating more road capacity [7–11].

Handover is a process in a vehicular communication environment for maintaining an active session while traveling from one coverage area to another without diminishing or disconnecting the session. Depending on the availability of network providers, handover can be selective or required. The primary goal of performing handover is to improve QoS parameters. A large number of handover decision techniques for mobile nodes such as V2I and V2X communications are available.

The main research issue for such studies is to avoid selecting the wrong candidate network for handover, as a result of insufficient information mostly at the terminal side. Not only do handover failures occur, but also unnecessary handovers can be witnessed. The inaccurate information regarding network providers can lead to unsuccessful communication since the standard handover is activated when the target network shows signal power greater than a certain threshold value [12].

Intelligent Transportation Systems (ITS) aim to provide traffic management that can intelligently react to changing traffic circumstances in real time while also operating in a dispersed environment. A biologically-based system that is both adaptable and evolutionary and adopts some of the traits of biological cells is one of the solutions to some of the traffic management difficulties.

Researchers employed the differential variant of the attractor selection model to enable congestion control and machine communication using multiple base stations. The approach is based on the concept of choosing appropriate base stations so that access can be spread according to the biological model as it is influenced by external factors. This might alleviate some of the congestion-related overload. To tackle the complexity of base station self-adaptation, the attractor selection model is applied [13].

The biological attractor selection model is also used for both router selection and video routing, where a multipath routing protocol for video transmission in IoVs is proposed. The objective of the model is to improve the efficiency and quality of video transmission by modeling the hopping mechanism using the bio-inspired attractor selection technique [14, 15].

Attractor selection is an adaptive feature displayed by Escherichia coli’s biological system (AS). As long as the surrounding conditions do not change, the AS system permits dynamic changes that result in performance stability due to the occupation of a stable state. Such a system will only allow transitions to new states as a result of changing conditions. Many traffic difficulties, including connectivity, vehicular communication, and message routing among vehicles and between vehicles and infrastructure, can be effectively addressed with such a mechanism.

The biological attractor selection mechanism is applied to multipath routing in mobile ad hoc networks (MANETS) in order to improve the selection of new routes under changing environments. The improvement is measured in terms of packet delivery ratio and average throughput [16].

The attractor selection technique is also used to reduce the problems faced with insufficient bandwidth used by power line wireless communication. The attractor selection algorithm (ASA) is used to find an optimal path with low latency and higher communication quality [17].

Research cases are carried out to allow for better management of different networks’ communication with wireless communication networks, mobile ad hoc networks, and are applied to vehicular networks by modeling connectivity as biological cell interaction. This interaction is based on the sharing of infrastructure and resources between cells (network service providers). This can be applied to vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication with real-time changing road conditions.

Biological system modeling of mobile and wireless networks is supported by the following biological system characteristics [18]:

(i) Adaptability to dynamic environmental conditions
(ii) Reliability and resistivity to functional and operational failures caused by internal factors
(iii) Ability to carry out complex processes using basic rules
(iv) Possessing the evolution and learning property to learn and respond to new surroundings and new events
(v) Having central intelligence with the ability to self-organize and achieve equilibrium and survive

These characteristics are exploited in vehicular communication such as V2I to achieve beamforming and to reduce instability in V2I communication due to the dynamic nature of vehicular movements. The attractor selection algorithm is used to adaptively modify the used beam width in order to respond to changing communication channel conditions and improve efficiency [19].

Modeling the Escherichia coli biological system necessitates adopting a change in its performance as a result of environmental factors involving outside signals that affect its biological system behavior. This is carried out by providing energy and nutrition to the cell or by restricting cell growth and interaction to what is equivalent to noise.

The biological system’s ability to shift and flip from one genetic condition to another is also included in the model, resulting in the generation of phenotypic states that adapt better to new environments and environmental changes. As a result of interactions, the dynamics fit within an attractor pattern, resulting in attractor states. The creation of such states makes the modeled biological system resistant to outside changes.

Such favorable property resulted in researchers modeling vehicular networks and traffic, where they used attractor selection technique for signal switching mechanism at
intersections. This approach extends well beyond conventional signal control. To achieve this, signalized intersections are modeled as biological cells, thus controlling traffic flow by the association of movements as the external dynamic changing environment. The objective is to reduce congestion and enhance efficiency [20].

In this work, network competitive connectivity for vehicles is modeled based on the Escherichia coli biological system that employs an attractor selection mechanism. If applied, it should result in a dynamical real-time system that adapts to changes in order to achieve stable, strong, and efficient connectivity. This will enable adaptive V2V and V2I communication as a function of changing environment.

The connectivity changes include signal strength, bandwidth, and stability over distance, attenuation, and fading. Adoption of the attractor selection technique (AST) will enable congestion control, mobility enhancement, and higher efficiency of traffic movement.

The presented approach differs from the others in that it allows networks to compete and collaborate in order to gain control of the networking environment by improving its QoS and at the same time handing over to other networks when it fails to do so under the attractor selection technique (AST).

The rest of this paper is divided as follows: Methodology, Results and Discussion, Conclusions, and References.

2. Methodology

One of the most difficult challenges in vehicular wireless networks is determining which network provides the best and most reliable connectivity in a dynamic, moving, and changing environment. Having a reliable network connection will allow vehicles to form networks for a short time to exchange messages with new vehicles and Road Side Units (RSUs).

Vehicles must frequently alter position and distance due to their inherent speed and direction characteristics. As a result, during the vehicle information transmission process, the vehicle must continue to alter its communication points. A vehicle blocks receiving services from its previously connected communication point and joins another to receive services during handoff or handover. More often than not, the vehicle links to a new communication network. At the time of handover, Vehicular Ad hoc Networks (VANETs), as expanded applications of Mobile Ad hoc Networks (MANETs), identify new routes to communicate. Rerouting is employed by the communicating vehicle in order to discover new communication points and sources. If the communication point is far, the communicating vehicle must depend on its neighbors for routing information, which necessitates an extra delay. The performance of this handover in terms of delay is critical to the Quality of Service requirement in VANETs. There are many challenges in vehicular communication systems, with the main issue being the handover management during mobile communication due to dynamic movements. The high mobility of vehicles and frequent topological changes in vehicular communication networks leads to an increase in the number of handovers, which could lead to a large number of handover failures [21].

Thus, connectivity and network provider selection should be based on efficiency as well as fair and stable allocation of network resources such as bandwidth and network speed. Conventional routing-oriented handover models and techniques are presented by researchers covering different aspects of routing, bandwidth, and multichannel communication in vehicular environments [22].

A biologically inspired handover model is presented by researchers. The authors proposed a model for decision-making in heterogeneous wireless networks. The objective of the model is to enable reliable multiterminal operation by optimizing QoS in response to each terminal requirement. In addition, the used attractor selection model attempted to guarantee balanced network resources distribution [23].

Research is also carried out covering the use of the biologically inspired technique (attractor selection) to facilitate the selection of appropriate networks and services depending on the stability and reliability of the biological systems [24]. Other researchers discussed offloading mobile data with increased efficiency using the attractor selection technique [25]. Others discussed multichannel and multihop communication using the attractor selection approach [26–28].

The methodology of this work is to consider vehicular networks with network providers using the attractor selection principles such that each connection is modeled as an individual biological cell. This approach models the competitiveness to provide Quality of Service (QoS) by network service providers. The biologically based survival and competitiveness system will enhance efficiency due to competition among network sources.

The competition will result in more stable connections that share the same environment and resources and dynamically adjust to external changes through the provision of new stable signal and connectivity levels. The used approach in this work is new in terms of competing networks to provide QoS and any network has to handover coverage if it falls below the required handover rank devised as a function of communication channel threshold and sensitivity.

The decision to stay as a provider or to handover is also related to selection probability that appeared in the original mathematical descriptor of Escherichia coli given by the expression in equation (1).

The used approach assumes a very low level of white Gaussian noise, which is necessary to match the biological model and to enable the separation of stable states offered by network service providers. The low-level noise can be ignored in the mathematical derivation without affecting the correctness of simulation and data interpretation. Table 1 shows the used nomenclature.
\[ \lambda(t + \Delta t) = \lambda(t) + \left( \left( \prod_{i=1}^{K} \frac{P}{(V_{\text{thrl}}/(N_i + V_i))^S_i + 1} \right) - C \ast \lambda(t) \right) \ast \Delta t. \] \tag{1}

Equation (1) can be simplified to obtain the following equation:

\[ \frac{(\lambda(t + \Delta t) - \lambda t)}{\Delta t} = \left( \left( \prod_{i=1}^{K} \frac{P}{(V_{\text{thrl}}/(N_i + V_i))^S_i + 1} \right) - (C \ast \lambda(t)) \right). \] \tag{2}

Three initial conditions can be applied to equation (2) for \( P = C \).

1. \( V_{\text{thrl}} = 0 \).

Equation (2) becomes

\[ \left( \frac{d\lambda}{dt} \right) = P - C \ast \lambda. \] \tag{3}

At steady state with stable condition \( (d\lambda/dt) = 0 \)

This gives \( \lambda = 1 \).

The value of 1 is not affected as a maximum probability of selection by the number of networks.

2. \( S_i = 0 \).

Equation (2) becomes

\[ \left( \frac{d\lambda}{dt} \right) = \frac{P}{2} - C \ast \lambda. \] \tag{4}

At steady state with stable condition, \( (d\lambda/dt) = 0 \) this gives \( \lambda = 0.5 \).

The \( \lambda \) value is dynamically affected by the number of networks, such that it adapts to the increase and decrease in available signal and competition between network service providers; this is shown in the following equation:

\[ \lambda(\text{Networks}) = \left( \frac{\lambda}{2^{(N-1)}} \right). \] \tag{5}

Thus, for \( 4 \)- networks and at \( S_i = 0 \),

\[ \lambda(\text{Networks}, S_i = 0) = \left( \frac{\lambda}{8} \right) = 0.0625. \] \tag{6}

3. \( S_i \rightarrow \infty \) and \( V_{\text{thrl}} \rightarrow \infty \).

This gives \( \lambda \rightarrow 0 \).

Testing of the set criteria for stable states under the attractor selection technique is carried out using MATLAB simulation.

3. Results and Discussion

Figures 1–11 present MATLAB simulation result showing the effect of threshold variation of probability of selection due to network activities and competition among network providers.

Table 2 summarizes the maximum network service provider stable state level as affected by changes in the threshold values. Threshold variations are found to be a good candidate to help characterize QoS, as it tests the connectivity against higher requirements of service provision.

A handover process is shown in Figures 1 to 11 and Table 2; as one network falls below the new threshold, the connection is handed over to another network in order to sustain vehicular connectivity either through the same device interface (homogenous) or using a different type of connectivity (heterogeneous). The handover process is shown in Figure 12.

Figures 13 to 23 and Table 3 present MATLAB simulation results showing the effect of sensitivity variation on the probability of selection due to network activities and competition among network providers.

Tables 4 and 5 summarize the maximum network service provider stable state level as affected by changes in the sensitivity values. Sensitivity variations are found to be another parameter to help characterize QoS, as it tests the connectivity against higher rates of variations in the surroundings, which requires higher levels of network connectivity and stability.

A handover process is shown in Figures 13 to 23 and Table 4; as one network falls below due to sensitivity changes, the connection is handed over to another network in order to sustain vehicular connectivity either through the same device interface (homogenous) or using a different type of connectivity (heterogeneous). The handover process is shown in Figure 24.
From Figures 12 and 24, it is observed that network activities (selection probability) have opposite trends when the threshold is increased versus when sensitivity is increased. Thus threshold and sensitivity are two important parameters that contribute to the provision of QoS as a function of the attractor selection algorithm. Working in opposite directions is an important trend as they will help in optimizing network connectivity selection and facilitate the handover process.
Tables 4 and 5 resent the ranking status of connectivity for four networks. Table 4 displays the ranking values as a function of the threshold, which is correlated to the probability selection values. The probability selection reflects the biological modeling of \textit{E. coli} as it functions on the principle of survival. This means that at least one network out of the four networks forming a matrix should have high-level, balanced, and stable signals with reliable thresholds.

Table 5 displays the ranking results as a function of sensitivity. These results are a result of the sensitivity effect. Such effect is reflected through the probability selection, which...
operates based on the biological *E. coli* model to counter any environmental and external changes by providing stable states, thus providing robust communication and efficient connectivity.

Table 6 shows a handover table resulting from the ranking process presented in Tables 4 and 5 reflecting threshold and sensitivity effects. The table displays the correlation between sensitivity, threshold, and selection.
This correlation is a core for the proposed handover technique as it enables the identification and ranking of stable states as a result of using the bioinspired approach. It is evident from Table 6 that the proposed model is verified as through simulation the selection probability value did not exceed 1 or fall below 0.0625. It is also evident from Table 6 that as the threshold value increases, the selection probability decreases. This is expected and is in line with the presented biological model. It is verified as through simulation the selection probability value did not exceed 1 or fall below 0.0625.
also clear that as the sensitivity values increase, the selection probability also increases as expected by the biological model.

Thus there is an inverse relationship between threshold and selection probability and there is a direct relationship between sensitivity and selection probability. Such a relationship will help in the adaptive behavior of the modeled system.

The ranking technique is used to enable the determination of the best threshold; sensitivity combination results in the formation of stable networks and stable states. The technique filters out transitional states and results in a set of networks with stable states. The technique functions as follows:

1. Classification of networks according to their signal level as a function of both threshold and sensitivity and selection probability.
2. Exclusion of networks with lower signal levels as a function of threshold or sensitivity or both and selection probability.
3. Inclusion of networks that have either the highest threshold or highest sensitivity or both with more than 0.5 selection probability.
4. Mapping and structuring of handover table of networks that possess both highest threshold and highest sensitivity with equal distributed signal levels (threshold, sensitivity) for the rest of the networks, thus producing stable states covering the four available networks.
5. Correlation of networks with the highest threshold and highest sensitivity to the selection probability.

Table 3 presents network selection according to the following:

1. Highest threshold or sensitivity signal levels.
2. Selection probability above 0.5.

From Table 7, the most balanced states per network are the ones with equal ranking for both threshold and sensitivity as shown in Table 8. The states that have unequal ranking as a function of threshold and sensitivity represent transient states as shown in Table 9 which will eventually settle in equal-ranked threshold and sensitivity pairs.

The reason behind choosing equal and balanced states per network is to have a final map and handover table that only shows handover between highest-ranking and balanced (stable) networks, which enables one network at a time to be used as a provider, thus enabling effective use of available bandwidth and encouraging competition among network providers to provide better QoS. Also, it enables transition within similar stable states per network provider.
Table 6: Network handover ranking map as a function of both threshold and sensitivity.

| Threshold $V_{th}$ | Sensitivity $S_L$ | Handover networks | Selection probability $\lambda$ |
|--------------------|-------------------|-------------------|-------------------------------|
| 0                  | 0                 | [1, 2] [3, 1] [4, 4] [2, 3] | [1.0, 0.0625] |
| 1                  | 1                 | [1, 1] [3, 4] [2, 2] [4, 3] | [0.9999, 0.5243] |
| 2                  | 2                 | [2, 2] [3, 4] [1, 1] [3, 3] | [0.9992, 0.8841] |
| 3                  | 3                 | [2, 2] [3, 3] [4, 4] [1, 1] | [0.9946, 0.9979] |
| 4                  | 4                 | [2, 2] [3, 4] [1, 1] [4, 3] | [0.9776, 0.9959] |
| 5                  | 5                 | [4, 4] [1, 1] [3, 3] [2, 2] | [0.9345, 0.9992] |
| 6                  | 6                 | [3, 3] [2, 2] [1, 1] [4, 4] | [0.8471, 0.9998] |
| 7                  | 7                 | [1, 1] [2, 2] [4, 3] [3, 4] | [0.7087, 0.9999] |
| 8                  | 8                 | [1, 1] [2, 2] [4, 4] [3, 3] | [0.5291, 0.9999] |

Table 7: Network handover ranking map as a function of threshold, sensitivity, and selection probability.

| Threshold $V_{th}$ | Sensitivity $S_L$ | Handover networks | Selection probability $\lambda$ |
|--------------------|-------------------|-------------------|-------------------------------|
| 1                  | 1                 | [1, 1] [3, 4] [2, 2] [4, 3] | [0.9999, 0.5243] |
| 2                  | 2                 | [2, 2] [3, 4] [1, 1] [3, 3] | [0.9992, 0.8841] |
| 3                  | 3                 | [2, 2] [3, 3] [4, 4] [1, 1] | [0.9946, 0.9979] |
| 4                  | 4                 | [2, 2] [3, 4] [1, 1] [4, 3] | [0.9776, 0.9959] |
| 5                  | 5                 | [4, 4] [1, 1] [3, 3] [2, 2] | [0.9345, 0.9992] |
| 6                  | 6                 | [3, 3] [2, 2] [1, 1] [4, 4] | [0.8471, 0.9998] |
| 7                  | 7                 | [1, 1] [2, 2] [4, 3] [3, 4] | [0.7087, 0.9999] |
| 8                  | 8                 | [1, 1] [2, 2] [4, 4] [3, 3] | [0.5291, 0.9999] |

Table 8: Final handover ranking of stable map as a function of both equal threshold and sensitivity values.

| Threshold $V_{th}$ | Sensitivity $S_L$ | Handover networks | Selection probability $\lambda$ |
|--------------------|-------------------|-------------------|-------------------------------|
| 3                  | 3                 | [2, 2] [3, 3] [4, 4] [1, 1] | [0.9946, 0.9979] |
| 5                  | 5                 | [4, 4] [1, 1] [3, 3] [2, 2] | [0.9345, 0.9992] |
| 6                  | 6                 | [3, 3] [2, 2] [1, 1] [4, 4] | [0.8471, 0.9998] |
| 8                  | 8                 | [1, 1] [2, 2] [4, 4] [3, 3] | [0.5291, 0.9999] |

Table 9: Network handover ranking of transitional states map as a function of threshold, sensitivity, and selection probability.

| Threshold $V_{th}$ | Sensitivity $S_L$ | Handover networks | Selection probability $\lambda$ |
|--------------------|-------------------|-------------------|-------------------------------|
| 1                  | 1                 | [1, 1] [3, 4] [2, 2] [4, 3] | [0.9999, 0.5243] |
| 2                  | 2                 | [2, 2] [3, 4] [1, 1] [3, 3] | [0.9992, 0.8841] |
| 4                  | 4                 | [2, 2] [3, 4] [1, 1] [4, 3] | [0.9776, 0.9959] |
| 7                  | 7                 | [1, 1] [2, 2] [4, 3] [3, 4] | [0.7087, 0.9999] |

Figure 25: Relationship between selection probability and number of networks.
time which possesses a stable threshold and stable sensitivity, thus enabling continuous connectivity that occurs through shielding against external and dynamic changes by stabilizing sensitivity, thus providing QoS.

Table 8 also illustrates the required threshold and sensitivity combinations that result in equal threshold and sensitivity occupying stable states for all networks. The final mapping covers all participating networks.

The handover technique looks at the available networks as a matrix, which enables tracing and handing over from one element (network provider with stable states) in a row in the matrix to another element in the matrix as the first element enters a transient state (unstable state), while the next element moves to stable state status.

The distribution of the selection probability adapts to the presence and number of networks competing and collaborating in the process of handover to guarantee continuous vehicular connectivity within a discrete environmental condition. Figure 25 shows effect of number of networks on $\lambda$ at $S_t = 0$.

The obtained relationship in equations (5) and (7) is used to redistribute selection probability in an adaptive manner in response to the number of participating networks.

$$\lambda(\text{Networks}, S_t = 0) = \exp(-0.6197 \times N_t).$$

The sensitivity and threshold descriptors discussed are critical for network selectivity and handover process when used in a bio-model. They are applicable within discrete levels of noise. Thus, each noise level changes the handover pattern as the competition changes according to the ability of each network service provider to sustain QoS within each noise level in a dynamic changing environment. Figures 26 to 28 show effect of noise on the handover process. The model adaptability and intelligence preserved the ability to continue handover within each noise level. However, the order of handover changes as a result of competition between networks under new environments.

4. Conclusions

In this work, an investigation of the applicability of the attractor selection algorithm to vehicular connectivity through simulation is carried out successfully. The objective of smooth handover between network service operators to cover both homogenous and heterogeneous networks is proved to work in principle.

The work presented two new Quality of Service parameters that affect network connectivity and showed through a change of threshold and sensitivity that a shift in the handover map occurs. The work also showed that the principles of E. coli survival and robustness are displayed through the adaptive behavior of the four simulated networks, whereby there is a guarantee that at least one network possesses stable levels under different surrounding conditions.

The effect of the two parameters (threshold and sensitivity) is reflected through a probability of selection parameter, which contributes towards system self-learning intelligent behavior. This means that continuous network coverage is assured under such a model. This supports stable networks and enables better communication, which
contributes to the efficiency and safety of vehicles on the road and supports the applications of connected and autonomous vehicles.

The presence of noise is found to affect signal levels, but, due to the adaptability of the biological model, it did not affect the handover process. The model intelligence and adaptable behavior is also demonstrated as the selection probability \( \lambda \) adapts to the number of participating networks.

**Data Availability**

Data are included within the submitted paper.

**Conflicts of Interest**

The author declares that there are no conflicts of interest.

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The MATLAB simulation in this work initially used the algorithm originally designed by Daxin Tian.

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