Journal of Intelligent Communication
https://ojs.ukscip.com/index.php/jic

Communication

Star-Connected Computer Network and Communication

Elman Mohammed Shahverdiev

Institute of Physics, Azerbaijan National Academy of Sciences, Baku 1143, Azerbaijan;
e.shahverdiev@physics.science.az

Received: 1 December 2025; **Revised:** 25 December 2025; **Accepted:** 29 December 2025; **Published:** 8 January 2026

Abstract: Star-connected computer networks are explored using the example of terahertz modeling. Existence conditions for the complete synchronization between constituent lasers are found numerically. Numerical simulations were conducted using the Matrix Laboratory (MATLAB) software to solve Delay Differential Equations. Extensive numerical simulations with different initial states confirm that high-quality, near-perfect complete synchronization between terahertz lasers occurs. As in the real world, parameters can differ; we simulated the star-connected computer network model with parameter mismatches of 3–5%. Still, we have obtained close to 100% of correlation between the dynamics of terahertz lasers. Synchronization is important in chaos-based communication. It is underlined that chaos-based communication security between computer networks can offer an additional layer of security to the traditional cryptography based on the Rivest, Shamir, and Adleman (RSA) algorithm. This algorithm uses the mathematical challenge of factoring very large prime numbers. The extra layer of security is of immense importance in light of the exponential increase in central processing units (CPUs) in computers. This is especially true in light of the quantum processing unit (QPU), which is the core processor of a quantum computer, using qubits in superposition and entanglement to perform complex, parallel calculations far beyond classical CPUs. Unlike traditional binary CPUs, QPUs excel at optimization, cryptography, and artificial intelligence tasks.

Keywords: Star Networks; Terahertz Model; Josephson Junctions; Time Delay Systems; Chaos Synchronization; Communication

1. Introduction

Synchronization of chaotic fluctuations is one of the powerful control methods in nonlinear dynamics; it is of certain importance in the scientific and technological fields, and the natural world [1,2]. It is well-known that some deterministic systems depending on parameters diapason could exhibit chaotic behavior. Nowadays, it is well established that such behavior could occur in nearly all scientific disciplines, such as physics, mathematics, biology, ecology, sociology, medical sciences, etc. Chaotic dynamics could be demonstrated in a system of three nonlinear ordinary differential equations, in logistic maps, etc. Historically, the Lorenz system of three ordinary differential equations was the first to be used for weather prognosis. Sensitive dependence of chaotic trajectory on the initial conditions (due to the positive Lyapunov exponent) makes long-term weather prediction impossible: low-dimensional systems trajectories behave as a system with fluctuations in a random manner [1].

Synchronization between systems can help to achieve higher-power lasers. This is especially important for the synchronization between terahertz sources (sometimes called terahertz lasers (THL)). Terahertz waves are spread over the electromagnetic spectrum from 100 gigahertz to 10 terahertz, although in the scientific literature, one may encounter a slightly different diapason.

In recent years, it was established that synchronization between terahertz sources based on Josephson junctions could be potentially helpful to achieve milli-watt powers. Such powers can be vital in creating adequate powers for practical applications. Synchronization between thousands and thousands of Josephson junctions present in high-temperature superconductors such as $Bi_2Sr_2CaCu_2O_8$ could be helpful in achieving this goal [3]. Although currently there are a lot of viable sources of terahertz radiation, such as gyrotron, the far infrared laser, the free electron laser, quantum cascade laser, etc., as a rule these sources of terahertz waves require a lot of space, are not portable, and importantly need expensive deep cooling procedures. These factors stimulate the need for developing compact, portable, and cheap (cost-effective) terahertz sources.

Nowadays, it is well established (as underlined above) that a Josephson junction emits terahertz radiation. Unfortunately, the radiation from a single Josephson junction is very weak, usually from pico- Watt to nano-Watt. Synchronization of the arrays (of networks) of Josephson junctions could be helpful to break these limitations. The energy gap in high-temperature superconducting materials (ceramics) ranges from 10 to 60 meV, which provides a frequency diapason from 5 to 30 terahertz. Most importantly, the Josephson junctions are homogeneous on an atomic scale. It means that coherent terahertz radiation is possible from such networks. It is called super radiation, when the power intensity from such a stack of arrays is proportional to the square of the number of Josephson junctions.

For the coupled chaotic systems, many different synchronization states have been studied. Complete or identical synchronization [4,5] was the first to be discovered and is the simplest form of synchronization in chaotic systems. In this type of synchronization, the dynamics of interacting systems after some transients coincide with each other. Other types of synchronization include: phase synchronization, when phases are synchronized, and amplitudes of interacting systems remain uncorrelated [6]. Lag synchronization [7] (in this synchronization, the driven (slave) system follows the dynamics of the driver (master) system with some time lag). In inverse synchronization, one dynamical variable synchronizes to the inverse value of the other dynamical system [8]. Some researchers use the term antiphase synchronization instead of inverse synchronization [9]. In generalized synchronization, there is some functional relation between the systems [10]. In dual and dual-cross synchronization, a pair of driver systems synchronizes to the pair of driven systems [11]. Cascaded (synchronization between a cascade of interacting systems) and adaptive synchronization (by choosing the coupling function or parameters between coupled systems adaptively), one can achieve such a type of synchronization [12–14]. In an anticipatory synchronization, the driven system anticipates the driver system [15].

Synchronization in complex systems is of a certain importance in governing and performance improvement from a point of view [16]. This is based on the fact that a chaotic attractor consists of an infinite number of periodic orbits, along which the nonlinear system's performance differs. Choosing the "right" periodic orbit, the system's yield can be optimized [16].

As synchronization means communication, a study of synchronization is of paramount importance in communicating networks [1]. Chaotic behavior could be of some advantage in enhancing the speed of chemical reactions via mixing, accelerating heat or matter mixing; additionally, sensitive dependence on initial conditions in chaotic systems could make such systems more governable, spending less energy. According to the modern medical approach, chaotic heartbeat rhythms are a more desirable signature of a healthier heart. In the construction business, chaotic vibrations could result in a collapse of buildings. In Josephson junction devices, used as a voltage standard, detectors, superconducting quantum interference applications, etc., chaotic instabilities are not desirable. However, chaotic Josephson junctions can be used for ranging purposes, along with numerous applications touched upon in this work [2]. Physiologically erratic, chaotic behavior could cause some tiredness.

While focusing on the positive side of the chaos synchronization, one should not forget about the situations when synchronization between interacting systems could be quite harmful. For example, in epileptic patients, synchronization between neurons could be the reason for epileptic seizures [17]. Anticipating synchronization could be quite helpful for diagnostic purposes, e.g., by anticipating epileptic seizures [15,18]. Another harmful influence of the synchronization occurred on the iconic London Millennium Bridge on the opening day due to the migration of pedestrians onto the bridge. The bridge has nearly collapsed and was immediately closed for the year-long repair work [19]. The main cause of the near-collapse situation was the pedestrian walkers' movements in-phase synchronization on the Millennium Bridge. Historically, there were many bridge collapses all over the world as a result of soldiers marching on the bridges in step [19].

This paper studies star-connected chaos synchronization based on the terahertz system-paradigmatic model of chaotic dynamics in time delay systems [2,20,21].

The originality and importance of this paper lie in spanning a bridge between chaos synchronization and star-like connected computer networks. Synchronization is important in chaos-based communication [1]. At the transmitter, a message is masked with chaos, and then this combined signal is transmitted to the receiver system. At the receiver, due to the chaotic synchronization between the transmitter and the receiver, chaos is regenerated. Deducting the receiver output from the receiver input, one can decode the transmitted message. An extra layer of security could be provided by such an approach to communicating data packets between the computers.

Due to the finite speed of information propagation between the interacting systems, feedback, switching, and memory effects, etc., time delay systems [20] are widely present in science and technology, in the natural world [20]. Because time delay systems are, in fact, infinite-dimensional (as initial conditions are given on the interval and the number of points is infinite), these systems can be used to describe partial differential equations. Most importantly, time delay systems (functional differential equations) are capable of generating hyper chaos–from the security point of view, a very attractive property for chaos-based communication systems [20,22]. Apart from this, these systems can be used to model space-time processes [20] and references therein. Time delay systems, especially with multiple time delays, are more attractive for communication purposes as they generate hyper chaos (with two or more positive Lyapunov exponents) [20–22] and references therein. In such systems, the values of the positive Lyapunov exponents are also larger in comparison with the case of time delay systems with a single time delay [15,20]. The value of positive Lyapunov exponents is also dependent on the value of time delays. In real-world applications, time delays could be modulated due to the fluctuations or deliberately [2].

In this paper, we consider a star-connected network topology. Existence conditions for the complete chaos synchronization are found numerically. We also provide extensive numerical calculations demonstrating the occurrence of synchronization between networks with different initial states. These findings are of certain importance in communication between computers, in obtaining high-power lasers.

2. Star-Connected Network Topology

In the star connected [23] network topology the nodes are described by the time delay systems based on the terahertz lasers. Lines connecting the nodes are called links. The network topology is a connection of nodes and links. **Figure 1** shows the schematic description of the star network.

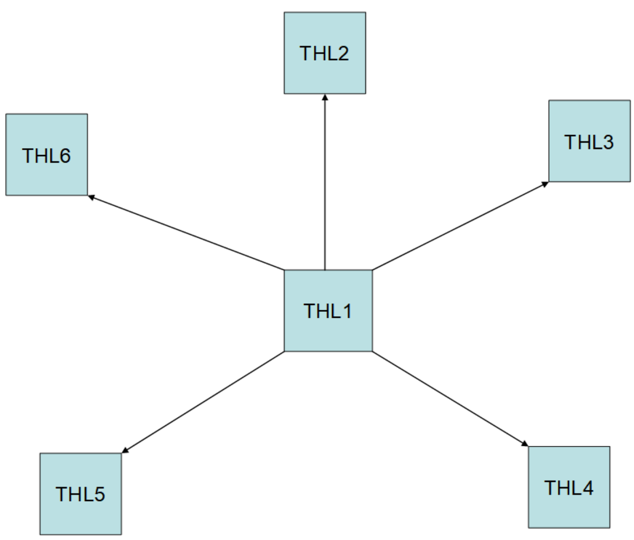

Figure 1. Schematic description of the star network topology.

Note: Node THL1 is the hub. Nodes THL2, THL3, THL4, THL5 and THL6 form peripheral nodes. As mentioned above THL stands for terahertz laser.

Consider the following set of terahertz sources based on Josephson junctions forming the star topology:

$$\frac{d\phi_1}{dt} = \Psi_1, \tag{1}$$

$$\frac{d\Psi_1}{dt} = -\beta\Psi_1 - \sin\phi_1 + i_{dc} + i_0\cos\varphi_1, \tag{2}$$

$$\frac{d\varphi_1}{dt} = \Omega, \tag{3}$$

$$\frac{d\phi_2}{dt} = \Psi_2, \tag{4}$$

$$\frac{d\Psi_2}{dt} = -\beta\Psi_2 - \sin\phi_2 + i_{dc} + i_0\cos\varphi_2 - \alpha(\Psi_2 - \Psi_1(t-\tau)), \tag{5}$$

$$\frac{d\varphi_2}{dt} = \Omega, \tag{6}$$

$$\frac{d\phi_3}{dt} = \Psi_3, \tag{7}$$

$$\frac{d\Psi_3}{dt} = -\beta\Psi_3 - \sin\phi_3 + i_{dc} + i_0\cos\varphi_3 - \alpha(\Psi_3 - \Psi_1(t-\tau)), \tag{8}$$

$$\frac{d\varphi_3}{dt} = \Omega, \tag{9}$$

$$\frac{d\phi_4}{dt} = \Psi_4, \tag{10}$$

$$\frac{d\Psi_4}{dt} = -\beta\Psi_4 - \sin\phi_4 + i_{dc} + i_0\cos\varphi_4 - \alpha(\Psi_4 - \Psi_1(t-\tau)), \tag{11}$$

$$\frac{d\varphi_4}{dt} = \Omega, \tag{12}$$

$$\frac{d\phi_5}{dt} = \Psi_5, \tag{13}$$

$$\frac{d\Psi_5}{dt} = -\beta\Psi_5 - \sin\phi_5 + i_{dc} + i_0\cos\varphi_5 - \alpha(\Psi_5 - \Psi_1(t-\tau)), \tag{14}$$

$$\frac{d\varphi_5}{dt} = \Omega, \tag{15}$$

$$\frac{d\phi_6}{dt} = \Psi_6, \tag{16}$$

$$\frac{d\Psi_6}{dt} = -\beta\Psi_6 - \sin\phi_6 + i_{dc} + i_0\cos\varphi_6 - \alpha(\Psi_6 - \Psi_1(t-\tau)), \tag{17}$$

$$\frac{d\varphi_6}{dt} = \Omega, \tag{18}$$

Where ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5 and ϕ_6 are the phase differences of the superconducting order parameter are across the junctions 1, 2, 3, 4, 5 and 6 respectively; Ψ_1, Ψ_2, Ψ_3, Ψ_4, Ψ_5, and Ψ_6, describe dynamics of ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5 and ϕ_6 respectively; β is called the damping parameter and is related to McCumber parameter β_c: $\beta^2\beta_c = 1$; i_{dc} is the driving the junctions direct current; $i_0\cos(\Omega t + \theta)$ is the driving ac (or rf) current with amplitudes i_0, frequencies Ω and phases θ; τ is the coupling time delay between Josephson junctions 1-2, 1-3, 1-4, 1-5, 1-6; α is the coupling strength between junctions. Note that in Equations (1)–(18) direct current and *ac* current amplitudes i_0 are normalized with respect to the critical currents for the relative junctions; *ac* current frequencies Ω are normalized with respect to the Josephson plasma frequency. Dimensionless time is normalized to the inverse plasma frequency.

It is worth mentioning an elegant derivation of Equations (1)–(3) [24]. We also give some typical values for the parameters of the Josephson junctions [24]. A typical value of emitted frequency by the Josephson junction is of the order of 10^{11} Hz; the value of the McCumber parameter β_c ranges from 10^{-6} to 10^{6}; typical values of β are in the diapason 10^{-3}–10^{3}; for high temperature superconductors $Bi_2Sr_2CaCu_2O_8 \beta < 1$ [25]. The coupling strength α between the junctions' changes in the range 10^{-4}–10^{2}; The Josephson junction plasma frequency is on the order of 100 GHz; Dimensionless i_d and i_0 changes from 10^{-6} to 10^{1}; non-dimensional Ω is around 10^{-2} and 6×10^{-1}. One should also emphasize that the typical value for the length scale of the Josephson junctions is around 1 μm.

We underline that equations describing Josephson junction's dynamics are of a multidisciplinary nature [2,24,25]. Equations (1)–(3) are also used for modeling a driven nonlinear pendulum, charge density waves with a torque, and a sinusoidal driving force.

We also emphasize that the coupling topology considered in this paper is completely different from the topology investigated where terahertz lasers were governed by the central terahertz source [2]. That paper mainly deals with varying time delay systems. In this paper we investigate the case of the star-connected topology formed by the terahertz lasers. Time delays in this work are constant.

3. Numerical Simulations

This section numerically demonstrates the principal possibility of complete chaos synchronization between star connected terahertz networks. Numerical simulations are conducted with the help of MATLAB software (R2008b) to solve delay differential equations. Synchronization quality is characterized by the cross-correlation coefficient C [2] between the dynamical variables. Correlation coefficients are given without any round-off after computer round-off of the errors with no human intervention. As it is proven in the scientific literature the best quality synchronization occurs if the system parameters are equal. We will also take into account this conjecture. Unfortunately, it is rather difficult to estimate the stability conditions analytically. That is why we recourse to extensive numerical simulations. But as in the real-world, parameters can differ, we simulated Equations (1)–(18) with parameter mismatches of 3–5%. Still, we have obtained close to 100 % of correlation between the dynamics of terahertz lasers. As regards the numerical simulations, it is worth noting that the initial states for dynamical variables are chosen differently. We simulate Equations (1)–(18) for the following parameters:

$$\beta = 0.25, \alpha = 0.45, \tau = 0.0001, i_{dc} = 0.3, i_0 = 0.7, \Omega = 0.6, \theta = 0$$

with initial states:

$$(\phi_1, \Psi_1, \varphi_1) = (1.1, 2.1, 0), \quad (\phi_2, \Psi_2, \varphi_2) = (1.2, 2.2, 0), \quad (\phi_3, \Psi_3, \varphi_3) = (1.3, 2.3, 0),$$
$$(\phi_4, \Psi_4, \varphi_4) = (1.4, 2.4, 0), \quad (\phi_5, \Psi_5, \varphi_5) = (1.5, 2.5, 0), \quad (\phi_6, \Psi_6, \varphi_6) = (1.6, 2.6, 0)$$

Figure 2 depicts dynamics of variable Ψ_1 .

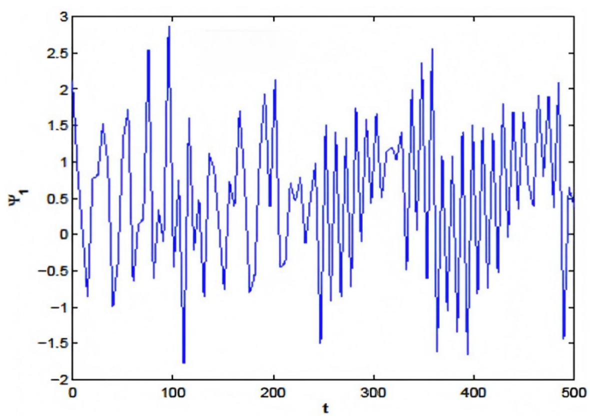

Figure 2. Chaotic dynamics of variable Ψ_1. Dimensionless units.

Figure 3 shows error dynamics Ψ_1–Ψ_2.

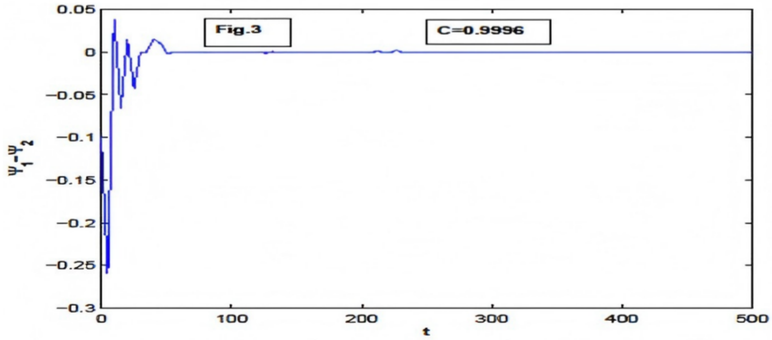

Figure 3. Error dynamics Ψ_1–Ψ_2.

Note: C = 0.9996 is the correlation coefficient between Ψ_1 and Ψ_2. Dimensionless units.

Figure 4 demonstrates dependence between Ψ_3 and Ψ_4.

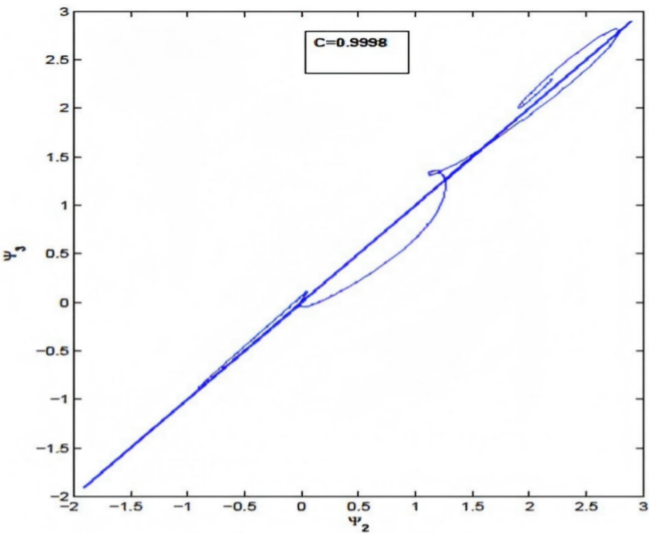

Figure 4. Linear dependence of Ψ_3 on Ψ_2.

Note: C = 0.9998 is the correlation coefficient between Ψ_3 and Ψ_2. Dimensionless units.

Figure 5 presents error dynamics Ψ_6–Ψ_2.

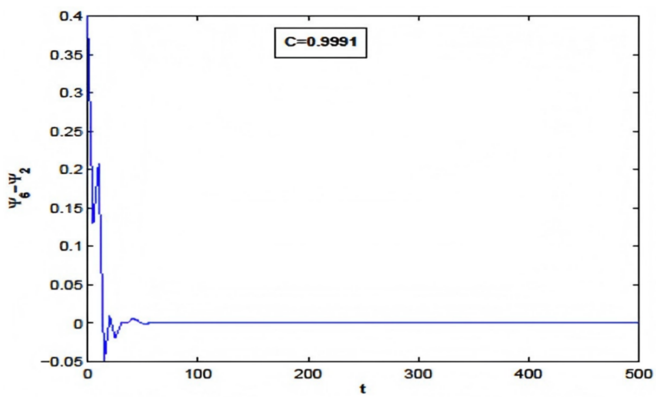

Figure 5. Error dynamics Ψ_6–Ψ_2.

Note: C = 0.9991 is the correlation coefficient between Ψ_2 and Ψ_6. Dimensionless units.

Numerical simulations show near-perfect complete chaos synchronization between the presented graphically cases, see **Figures 3–5**. Below for completeness in **Table 1** we present the correlation coefficients between all the nodes.

Table 1. Correlation coefficients between all the nodes.

C (Ψ_1,Ψ_2) = 0.9996	C (Ψ_1,Ψ_3) = 0.9990	C (Ψ_1,Ψ_4) = 0.9985
C (Ψ_1,Ψ_5) = 0.9983	C (Ψ_1,Ψ_6) = 0.9983	C (Ψ_2,Ψ_3) = 0.9998
C (Ψ_2,Ψ_4) = 0.9995	C (Ψ_2,Ψ_5) = 0.9993	C (Ψ_2,Ψ_6) = 0.9991
C (Ψ_3,Ψ_4) = 0.9999	C (Ψ_3,Ψ_5) = 0.9998	C (Ψ_3,Ψ_6) = 0.9995
C (Ψ_4,Ψ_5) = 0.9999	C (Ψ_4,Ψ_6) = 0.9997	C (Ψ_5,Ψ_6) = 0.9999

4. Discussions

There exist many types of topological connections between the systems, including terahertz lasers and computer networks, such as a ring-like connection, a star-like connection, a bus topology, a fully connected topology, a mesh topology, a hybrid topology, etc. [26–28]. These topologies could be made artificially or naturally [24,25]. Depending on the task in mind, the performances of these topologies might be different. Having in mind different possible ways of synchronization, including chaotic synchronization, a new research direction could be followed. Usually, transmission rates for star topology are less than 1 gigabit per second [26–28]. At the same time, it is worth mentioning that indoor wireless communication with terahertz may provide multiple data channels with gigabit per second capacity or even greater capacity. Terahertz waves can be used in wi-fi systems, satellite-to-satellite or satellite-to-Earth communications. In optical communication, one significant problem is the attenuation caused by scattering and absorption by clouds, rain, dust, etc. [29]. However, terahertz waves experience much less scattering loss. Terahertz communications can be used as a backup to the optical link in case of rain, heavy clouds, etc. In other words, terahertz communication can be used for short distances, if these particulars (such as dust, smoke, rain, heavy clouds) are present in the air [29]. Atmospheric transmission diapason might allow short-range tactical communication. In certain circumstances, limited range communication may be even an advantage, say in combat zones [29]. The beamlike property of terahertz communication could reduce the capability of distant enemies to intercept these transmissions. The enemy might be in a difficult position to detect, intercept, or jam these terahertz signals. These scenarios may be of immense interest in the fight against terrorism, the saving or rescuing of downed pilots, in covert operations, etc. That is why it is very important to have cost-effective, easily portable terahertz radiation sources. The results of this work could be of immense importance. Data exchange rate between computer networks is a very important factor. In terahertz communications [29]: (a) effective data exchange rates exceeding 1 Tbit/s (usually on an optical carrier) can be realized; (b) communication with a Terahertz carrier wave [29,30] is also possible. In the case of optical cables between the networks, data rates could be even higher than 1 terabit per second. This is due to the fact that the wave division multiplexing approach [30] can be exploited. In this approach, data packets can be sent using multiple wavelengths. Paper [30] was the first successful field experiment of chaos-based communication. An optical carrier generated by a chaotic laser was used to encode a message for transmission over 120 km of optical fiber in the metropolitan area of Athens. Transmission rates of gigabits per second were achieved. Field experiments have shown that the information can be transmitted in a way that is robust to perturbations and channel disturbances unavoidable under real-world conditions [30]. Terahertz radiation, as mentioned above, is situated between the millimeter waves and the far-infrared region. This radiation has many unique properties, such as a strong sensitivity to polar liquids, high transmission through a range of non-conducting materials, and a spectroscopic response to many materials. Terahertz imaging and spectroscopy systems provide new opportunities in addressing environmental issues, such as detection of environmentally dangerous objects (explosives, unexploded ordnances, landmines, hazardous chemicals, and biological objects), non-destructive imaging of concealed items, inhomogeneous systems (biological samples, or industrial products), process monitoring, and waste materials reduction [3] and references therein. Many of these applications require compact and mobile terahertz radiation sources. The study of synchronization between the Josephson junctions conducted in this work may be considered a step in the right direction and could pave the way to move out of the laboratory to real-world applications. In high-temperature Josephson junction-based terahertz sources, operating temperatures are usually in the diapason of 77–80 K [3]. Such operating temperatures can be conveniently achieved by a relatively inexpensive commercial cryocooler, an important step toward attaining a cheaper, compact, and portable high-temperature superconducting terahertz imager. High-temperature superconducting devices could also be used as a detector in astrophysics applications [3].

5. Conclusions

In this work, we investigated complete chaos synchronization in a terahertz-based computer network. As attested by the numerical simulations (see **Figures 2–5** and **Table 1**) very high quality of complete synchronization is reached.

We spanned the bridge between chaos control methods and the widely used computer, the star network topology. This is a novel approach to connect chaos synchronization and computer network(s) topology. As mentioned earlier, synchronization is vital in a chaos-based communication system to decode the transmitted message [1]. A chaos-based communication approach could provide an extra layer of security in data exchange between communicating computer networks. We also briefly dwell on the advantages and disadvantages of the star network topology architecture [23,26–28]. In this paper, the star topology is studied in local area networks, such as home networks, Automated Teller Machine networks in bank transactions, hospital networks, and Closed-Circuit TV networks, mainly for surveillance and security purposes. Among the advantages of star topology, one can emphasize [23,26–28]: 1) if one peripheral node or its connection fails, the other nodes are still operable; 2) new devices can be removed and added without disturbing the entire network; 3) applicable for a large network; 4) easy to manage, etc. Among the drawbacks of the star topology, one should mention [23,26–28]: 1) the central hub is the bottleneck; 2) very expensive, etc. Wiring the star network topology can be implemented with the optical fiber cable and twisted pair cable. In the former case, high-speed communication can be achieved. Usually, transmission rates for star topology are less than 1 gigabit per second [23]. Investigated in this paper, the configuration of high temperature Josephson junction-based terahertz sources could serve as a building block (motifs) for much more complex and sophisticated network(s) and computer architecture [31–35]. It is well-known that computers (including networks of computers) communicate via electric or light signals. Terahertz and optical signals are an important part of more speedy data exchange between the computer networks [23,26–28]. With increasing number of Central Processing Units, especially in light of the generation of qubits enabling exponential computing power, traditional ways of securing an information exchange could be under threat. In this context, an extra layer of security supplied by chaos-based communication in computer networks might be of certain importance [36–38].

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be made available on request.

Acknowledgments

The author appreciates the anonymous reviewers for their insightful and constructive remarks on the earlier draft of the manuscript, which helped to improve the current paper.

Conflicts of Interest

The author declares no conflict of interest.

References

1. Schoell, E.; Schuster, H.G. *Handbook of Chaos Control*, 2nd ed; Wiley-VCH: Weinheim, Germany, 2007; pp. 1–849.
2. Shahverdiev, E.M. Modulated Time Delays, Synchronized Josephson Junctions in High-Temperature Superconductors and Chaotic Terahertz Waves. *J. Supercond. Nov. Magn.* **2021**, *34*, 1125–1132. [CrossRef]
3. Nishijima, S.; Eckroad, S.; Marian, A.; et al. Superconductivity and the environment: a Roadmap. *Supercond. Sci. Technol.* **2013**, *26*, 113001. [CrossRef]
4. Pecora, L.M.; Carroll, T.L. Synchronization in Chaotic Systems. *Phys. Rev. Lett.* **1990**, *64*, 821–824. [CrossRef]
5. Shahverdiev, E.M.-O. Boundedness of Dynamical Systems and Chaos Synchronization. *Phys. Rev. E* **1999**, *60*, 3905–3909. [CrossRef]
6. Rosenblum, M.G.; Pikovsky, A.S.; Kurths, J. From Phase to Lag Synchronization in Coupled Chaotic Oscillators. *Phys. Rev. Lett.* **1997**, *78*, 4193–4196. [CrossRef]
7. Shahverdiev, E.M.; Sivaprakasam, S.; Shore, K.A. Lag Synchronization in Time-Delayed Systems. *Phys. Lett. A* **2002**, *292*, 320–324. [CrossRef]
8. Shahverdiev, E.M.; Nuriev, R.A.; Hashimova, L.H.; et al. Complete Inverse Chaos Synchronization, Parameter Mismatches and Generalized Synchronization in the Multi-Feedback Ikeda Model. *Chaos Solitons Fractals* **2008**, *36*, 211–216. [CrossRef]
9. Ghosh, S.; Sar, G.K.; Majhi, S.; et al. Antiphase Synchronization in a Population of Swarmalators. *Phys. Rev. E* **2023**, *108*, 034217. [CrossRef]
10. Shahverdiev, E.M.; Shore, K.A. Generalized Synchronization in Time-Delayed Systems. *Phys. Rev. E* **2005**, *71*, 016201. [CrossRef]
11. Shahverdiev, E.M.; Sivaprakasam, S.; Shore, K.A. Dual and Dual-Cross Synchronizations in Chaotic Systems. *Opt. Commun.* **2003**, *216*, 179–183. [CrossRef]
12. Mercadier, J; Doumbia, Y; Bittner, S; et al. Optical chaos synchronization in a cascaded injection experiment. *Opt. Lett.* **2024**, *49*, 2613-2616. [CrossRef]
13. Khattar, D.; Agrawal, N.; Singh, G. Chaos Synchronization of a New Chaotic System Having Exponential Term Via Adaptive and Sliding Mode Control. *Differ. Equ. Dyn. Syst.* **2025**, *33*, 475–493. [CrossRef]
14. Liu, J.; Zuo, T. Deep Adaptive Chaos Synchronization Based on Optimization Algorithm. *IEEE Access* **2025**, *13*, 38671–38684. [CrossRef]
15. Voss, H.U. Anticipating Chaotic Synchronization. *Phys. Rev. E* **2000**, *61*, 5115–5119.
16. Ott, E.; Spano, M. Controlling Chaos. *Phys. Today* **1995**, *48*, 34–40. [CrossRef]
17. Ditto, W.L.; Showalter, K. Introduction: Control and synchronization of chaos. *Chaos* **1997**, *7*, 509-511. [CrossRef]
18. Sivaprakasam, S.; Shahverdiev, E.; Spencer, P.; et al. Experimental Demonstration of Anticipating Synchronization in Chaotic Semiconductor Lasers with Optical Feedback. *Phys. Rev. Lett.* **2001**, *87*, 154101. [CrossRef]
19. Eckhardt, B.; Ott, E.; Strogatz, S.H.; et al. Modelling walker synchronization on the Millennium Bridge. *Phys. Rev. E* **2007**, *75*, 021110. [CrossRef]
20. Yanchuk, S.; Giacomelli, G. Spatio-Temporal Phenomena in Complex Systems with Time Delays. *J. Phys. A: Math. Theor.* **2017**, *50*, 103001. [CrossRef]
21. Kinzel, W. Chaos in networks with time-delayed couplings. *Philos. Trans. A Math Phys. Eng. Sci.* **2013**, *371*, 20120461. [CrossRef]
22. Ghosh, D.; Banerjee, S.; Chowdhury, A.R. Synchronization between variable time-delayed systems and cryptography. *Europhys. Lett.* **2007**, *80*, 30006. [CrossRef]
23. Star Topology. Available online: https://www.sciencedirect.com/topics/computer-science/star-topology (accessed on 1 June 2025).
24. Strogatz, S.H. *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*, 3rd ed.; Chapman and Hall/CRC: Boca Raton, FL, USA, 2024. [CrossRef]
25. Lin, S.-Z. Mutual Synchronization of Two Stacks of Intrinsic Josephson Junctions in Cuprate Superconductors. *J. Appl. Phys.* **2014**, *115*, 173901. [CrossRef]
26. What is network topology? Available online: https://www.ibm.com/think/topics/network-topology (accessed on 1 December 2025).
27. Network Topology. Available online: https://www.sciencedirect.com/topics/computer-science/network-topology (accessed on 1 December 2025).
28. Types of network topology. Available online: https://www.geeksforgeeks.org/computer-networks/types-o

f-network-topology (accessed on 1 December 2025).
29. Fitch, M.J.; Osiander, R. Terahertz waves for communications and sensing. *J. Johns Hopkins APL Tech. Dig.* **2004**, *25*, 348–355.
30. Argyris, A.; Syvridis, D.; Larger, L.; et al. Chaos-Based Communications at High Bit Rates Using Commercial Fibre-Optic Links. *Nature* **2005**, *438*, 343–346. [CrossRef]
31. Ki, E.-J.; Shin, S.; Oh, J. The State of Environmental Communication Research: An Analysis of Published Studies in the Communication Disciplines. *J. Intell. Commun.* **2022**, *2*. [CrossRef]
32. Kallas, K.; Tannous, C.; Faraoun, H. A Zero-Sum Game-Theoretic Analysis for CostAware Backdoor Attacks and Defenses in Deep Learning. *J. Intell. Commun.* **2025**, *4*, 74–92. [CrossRef]
33. Kanthavel, R.; Dhaya, R.; Ahilan, A. AI-Based Efficient WUGS Network Channel Modeling and Clustered Cooperative Communication. *ACM Trans. Sen. Netw.* **2022**, *18*, 1–14. [CrossRef]
34. Baek, S.-H.; Walsh, N.; Chugunov, I.; et al. Centimeter-Wave Free-Space Neural Time-of-Flight Imaging. *ACM Trans. Graph.* **2023**, *42*, 1–18. [CrossRef]
35. Krishna Moorthy, S.; Mcmanus, M.; Guan, Z. ESN Reinforcement Learning for Spectrum and Flight Control in THz-Enabled Drone Networks. *IEEE/ACM Trans. Networking* **2022**, *30*, 782–795. [CrossRef]
36. Lei, D.; Lin, X.; Yu, X.; et al. Privacy preserving optimization of communication networks. *Nat. Commun.* **2025**, *16*, 8501. [CrossRef]
37. Parastesh, F.; Mehrabbeik, M.; Rajagopal, K.; et al. Synchronization stability in simplicial complexes of near-identical systems. *Phys. Rev. Research* **2025**, *7*, 033039. [CrossRef]
38. Fang, F.; Ma, J.; Ma, Y.-J.; et al. Social contagion on higher-order networks: The effect of relationship strengths. *Chaos Solitons Fractals* **2024**, *186*, 115149. [CrossRef]