A survey on set-membership filtering for networked control systems under communication protocols

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ABSTRACT
In recent years, the set-membership filtering problem has received extensive research interests due to its engineering significance to estimate a set which includes the true state of the system rather than a single vector. What’s more, the communication protocol has been widely applied in the control systems because of its ability to prevent from data collisions and reduce the burden of the network. From the engineering practice, it is of vital importance to investigate the set-membership filtering under communication protocols. In this paper, a bibliographical review is provided on the set-membership filtering for networked control systems (NCSs) under communication protocols. Next, the concept of the NCS is briefly introduced. Some recent advances on the set-membership filtering problem for NCSs are summarized. Then, some well-known scheduling schemes are presented and the results of the set-membership filtering for NCSs under communication protocols are reviewed. Finally, some concluding remarks are given and some potential future research directions are pointed out.

1. Introduction
The past decades have witnessed that the filtering problem has been a seductive research focus attracting constant attention in the field of control communities and signal processing. Some common filtering methods include Kalman filtering (Li, Kar, Alsaadi, Dobaie, & Cui, 2015; Safarinejad & Yousefi, 2015), extended Kalman filtering (Ahmada & Namerikawa, 2013; Chatterjee, Fournier, Nait-Ali, & Siarry, 2010; Hu, Wang, Gao, & Stergioulias, 2012; Kluge, Reif, & Brokate, 2010), $H_\infty$ filtering (Dong, Wang, Ding, & Gao, 2016; Dong, Wang, & Gao, 2013; Dong, Wang, Shen, & Ding, 2016; Shen, Wang, Hung, & Chesi, 2011), $H_2$ filtering (Gao, Lam, Xie, & Wang, 2005; Liu, Liu, Shi, & Wang, 2014; Sahebsara, Chen, & Shah, 2007) and so on. Most of these filtering methods require the system noise including process noise and measurement noise to be in a random framework and provide a probabilistic state estimation. The probability properties of the estimation results are used to describe the state spreads (distributions) by means of mean and variance. These filtering algorithms do not guarantee that states are contained in the certain region because they are not hard bounds. Nevertheless, in many practical applications, such as system guidance and navigation, target tracking and attack, they require a confidence level of 100% to estimate. This leads to the state estimation of the ellipsoid. The idea of the ellipsoidal state estimation is to give a set of state estimates by assuming hard bounds in state space instead of stochastic descriptions on the system noises which always affect the true state of the system. These methods are therefore known as set-membership or set-valued state estimation (filtering) (Bertsekas & Rhodes, 1971; Morrell & Stirling, 1991). The origin of set-membership filtering can be traced back to 1960s (Witsenhausen, 1968) and the corresponding problems have attracted the growing interest of many researchers.

On the other hand, the networked control systems (NCSs) have become more and more prevalent due primarily to their extensive applications in many practical areas such as environmental monitoring, industrial automation, smart grids and distributed/mobile communications. It is the main characteristic of the NCSs to realize the connection of the system components through the shared communication networks. NCSs possess many advantages including low cost, simple installation, reduced system wiring and high reliability. However, the utilization of communication networks has made the analysis and design of the system more complicated (Krtolica, Ozguner, Chan, & Goktas, 1994;
Zhivoglyadov & Middleton, 2003) and has led to rich yet complex network-induced behaviours such as signal quantization, missing/fading measurements, communication delays, sensor saturations and out-of-sequence-measurement updates. These behaviours have gained considerable research attention as introduced in Bahreini and Zarei (2016), Hassani and Zarei (2016), Li, Dong, Han, Hou and Li (2017), Gholami and Binazadeh (2018), Yu, Dong, Wang, Ren, and Alsaaadi (2016), Yang, Dong, Wang, Ren, and Alsaaadi (2016), Li and Bao (2017), Dong, Wang, Ding, and Gao (2014) and Shen, Song, Zhu, and Luo (2009). Hence, it has important practical significance to discuss the set-membership filtering problem for the NCSs.

Many existing literatures usually assume that all the sensor nodes could get access to the network to transmit signals at the same time, but this is impossible in the real world due to the limited network bandwidth. The communication protocol has been introduced to prevent the data from collisions where all the sensor nodes transmit signals according to the scheduling of the employed protocol. Due to the difficulties in dealing with the coupling issues between the set-membership filtering and the protocol scheduling, the set-membership filtering problems for the NCSs under communication protocols have gained growing research interests.

The set-membership filtering problems for the NCSs under communication protocols have been mainly investigated in this paper and the latest progresses in this field have been reviewed. Several common protocols include stochastic communication protocol (Tabbara & Nesic, 2008), Round-Robin (RR) protocol (Ugri novskii & Fridman, 2014) and Weighted Try-Once-Discard (WTOD) protocol (Donkers, Heemels, van de Wouw, & Hetel, 2011). First of all, the modelling issues are first discussed to reflect the characteristics of the NCSs. Based on the establishment of the model, the set-membership filtering problems for the NCSs are discussed in detail. Then, the system models are processed according to the scheduling of different communication protocols. This paper first introduces the features of the NCSs. Subsequently, the set-membership filtering problems for the NCSs under communication protocols have been given a particular attention through summarizing recent results in this field. Finally, some conclusions are drawn and some related research directions are pointed out.

The remainder of this paper is organized as follows. The concept of the NCSs is briefly introduced in Section 2. Section 3 reviews the set-membership filtering problems for NCSs and applications. Various kinds of communication protocols are discussed and the corresponding results are summarized in Section 4. The conclusions and future work are given in Section 5. The concrete structure of this paper can be seen in Figure 1.

2. Networked control systems

In the last several years, with the popularity of the Internet and the booming phenomenon of network technology, the utilization of the network in control systems has dramatically increased (Ding, 2011) and (Luo & Chen, 2012). Control loops that are closed connected
by the communication network have become more and more common because the hardware devices for the network and network nodes have become cheaper. A control system communicating with sensors and actuators via a communication network is called an NCS, see Figure 2 for a typical NCS setup and its information flows (Zhang, Branicky, & Phillips, 2001). The traditional communication architecture used in industry is point-to-point, in which a central control computer is connected to each sensor or actuator point by a single line. However, as physical settings and functions continue to expand, point-to-point approaches no longer meet new requirements, such as modularization, decentralized control, integrated diagnostics, easy maintenance and low cost. Hence, the NCS has attracted increasing attention from many researchers because it has a relatively new structure where sensors, controllers and plants are often connected over a shared bandlimited digital communication network (Hespanha, Naghshtabrizi, & Xu, 2007). Using multipurpose shared network to connect spatial distribution elements makes the NCS have some advantages such as flexible architecture, low cost of installation and maintenance and so on. Meanwhile, the NCS is widely used in a broad range of areas like remote surgery (Meng et al., 2004), automated highway systems, unmanned aerial vehicles (Seiler & Sengupta, 2001) and mobile sensor networks (Ogren, Fiorelli, & Leonard, 2004). However, the use of the shared network brings convenience, but also adds new challenges to the research of system performance. Obviously, the tasks in traditional systems, such as the control problem and signal estimation problem should be reconsidered due to the introduction of the network.

As is well known, due to the introduction of the communication network with limited communication capacity, the network-induced phenomena arise inevitably. Such network-induced phenomena include, but are not limited to, signal quantization (Dong, Wang, Ding, & Gao, 2015; Wang, Dong, Shen, & Gao, 2013), missing/fading measurements (Ding, Wang, Lam, & Shen, 2015; Ding, Wang, Shen, & Dong, 2015a,1; Wang, Ding, Dong, & Shu, 2013), communication delays (Hu, Chen, & Du, 2014; Shen, Wang, & Tan, 2017; Wang, Liu, Shen, Alsaadi, & Abdullah, 2017), variable sampling/transmission intervals, sensor saturations and out-of-sequence-measurement updates (Hu, Wang, Chen, & Alsaadi, 2016; Shen et al., 2009). In particular, a class of emerging network-induced phenomenon (randomly occurring incomplete information) has obtained preliminary research interest in the field of signal processing and control. It is noted that network-induced phenomena can greatly deteriorate the performance of the NCSs and can even lead to instability of the control system. Therefore, it is not surprising that the analysis and synthesis of the NCSs in the past decade have attracted considerable interests.

3. Set-membership filtering for networked control systems

It is well known that the filtering plays an important role in signal processing (Anderson & Moore, 1979). The famous Kalman filtering requires the process and measurement noises to be white Gaussian processes (Kalman, 1960). The $H_\infty$ filtering provides an energy gain for the estimation error in the worst case without the need of noise statistical knowledge (Zames, 1981). However, the Kalman filtering may cause poor performance for non-Gaussian noises (Yang, Wang, & Hung, 2002) and the $H_\infty$ filtering
does not specify that the variance of the state estimation error is within an acceptable range (Yang & Hung, 2002). Bearing this in mind, it is natural to regard process noise and measurement noise as unknown but bounded noises belonging to a given set in the appropriate vector space (Morrell & Stirling, 1991; Schwepe, 1968). All possible state estimates can be described in terms of a set of state estimates that match both the received measurements and the constraints on the unknown but bounded noises whose norm is less than the specified scalar, and the real state is included in the set of state estimates. Such an estimation problem is called a set-membership (set-valued) filtering problem.

The set-membership filtering problem was first presented by Witsenhausen (1968) and Schwepe (1968). The set of all possible values for all states which are compatible with output measurements is described by their support functions. Then, the concept of set-membership estimation has been developed rapidly at the end of the 1960s and the beginning of 1970s, see (Bertsekas & Rhodes, 1971; Schwepe, 1968). Compared with other filtering methods, the set-membership filtering approach has two significant advantages: (1) it requires a hard bound constraint rather than the statistical description on the system noises; and (2) it is capable of providing a set of ellipsoidal sets that contain all possible actual states with 100% confidence. In fact, the statistical information of noise is not available due to unpredictable environmental changes and can only give boundedness. In addition, in the engineering practice, it is usually necessary to estimate the upper limit of estimation error accurately and try to be as small as necessary. Therefore, the estimation method derived in the mean square sense may not meet the actual needs at times, and the set-membership filtering method shows its advantages under such circumstances. In the past decades, scholars have done a lot of work which was mainly about computing the set of states that contains a given disturbance and noise. From a technical point of view, such a set can be a convex polyhedron which is usually described as a variety of simple shapes, such as ellipsoids (El. Ghaoui & Calafiore, 2001; Polyak, Nazin, Durieu, & Walter, 2004; Wei, Liu, Song, & Liu, 2015; Wei, Liu, Wang, & Wang, 2016), parallelotopes (Chisci, Garulli, & Zappa, 1996; Vicino & Zappa, 1996) or zonotopes (Alamo, Bravo, & Camacho, 2005; Alamo, Bravo, Redondo, & Camacho, 2008). The specific descriptions of these methods are listed in Table 1. Many systematic methods have been developed to deal with the issue of set-membership filtering including interval analysis method, convex optimization method and so on.

It is worth mentioning that, besides the commonly used ellipsoidal state bounding region, the parallelotopic state bounding region is also an important set-membership performance index. Moreover, many relevant results have been published. For example, a novel approach based on minimum-volume bounding parallelotopes has been introduced in Chisci et al. (1996), where an algorithm of polynomial complexity has been derived. In Bemporad and Garulli (2000), a minimum-volume parallelotopic approximation has been designed for the worst situation compatible with the available information, where the constraint fulfilment is guaranteed and the asymptotic stability properties of the system are preserved. A recursive procedure has been presented in Vicino and Zappa (1996) for providing an approximation of the parameter set of interest through parallelotopes.

### 3.1. Set-membership filtering for networked control systems

In recent years, the set-membership filtering problem for NCS has attracted considerable research interests and the correlative results have been published. According to the linear system and nonlinear system, we review the results of the set-membership filtering as follows.

#### 3.1.1. Set-membership filtering for a linear system

Due to the low difficulty in the linear system, scholars have done a lot of research on the set-membership filtering problems for linear systems, and many related literatures have been published. In Gollamudi, Nagaraj, Kapoor, and Huang (1998), a new formulation for linear-in-parameter filtering has been introduced, which represents a specified constraint to estimate a set of feasible filter parameters to meet the estimation error, a toolbox of adaptive algorithms for set-membership filtering, called SMART, also has been presented. The set-membership filtering methods have been used to solve the problem for estimating the state of a continuous-time linear system in Bertsekas and Rhodes (1971) and a discrete-time linear system in Poljak, Nazin, Durieu, and Walter (2002), respectively. In El. Ghaoui and Calafiore (2001), the convex optimization method has been employed to deal with the set-membership filtering for a class of norm bounded uncertainty system. In Ra, Jin, and Park (2004) and Savkin and Petersen (1995, 9), a recursive method for

### Table 1. Description methods.

| Types            | Mathematical description                                                                 |
|------------------|------------------------------------------------------------------------------------------|
| Ellipsoid        | $E(c, P) = x : (x - c) \parallel P(x - c) \leq 1$                                       |
| Parallelootope    | $\mathcal{T}(\tau, x) = x, x = x + T \alpha \parallel \| \alpha \|_\infty \leq 1$          |
| Zonotope          | $p \in H B^m = p + Hz, z \in B^m$                                                        |

* $P \geq 0 \quad T = \left[ t_1, t_2, \ldots, t_b \right] \in \mathbb{R}^{n \times N}, \quad \hat{x}, c, p \in \mathbb{R}^n$ and $H \in \mathbb{R}^{n \times m}$* ** The vector $c$ and $\hat{x}$ are the centres of the above shapes, respectively. A unitary box in $\mathbb{R}^n$, denoted as $B^m$, is a box composed by $m$ unitary intervals.
constructing an ellipsoid state estimation set which is consistent with the measured output and the given noise has been proposed. The set-membership filtering problems have been investigated in Xia, Yang, and Han (2016) and Wei et al. (2015) for a class of discrete time-varying systems with partial information transmission or with incomplete measurements.

3.1.2. Set-membership filtering for nonlinear system
Compared with linear set-membership filtering method, the set-membership filtering method of a nonlinear system is difficult to calculate, mainly due to the complexity of feasible set under nonlinear transformation. It is this complexity that attracts many scholars to study the set-membership filtering for nonlinear systems. Some results also have been reported in the literatures. The set-membership filtering problems have been addressed in Yang and Li (2009b), Ma, Wang, Lam, and Kyriakoulis (2017), Wei et al. (2016), Wu, Wang, and Ye (2013) and Yang and Li (2009a) for a class of nonlinear discrete-time systems with saturation effects or equality constraints in the presence of unknown but bounded process and measurement noises. In Yang and Li (2010), a new nonlinear set-membership filtering estimation method by using the fuzzy modelling approach and the S-procedure technique has been developed to determine a state estimation ellipsoid that is a set of states compatible with the measurements, the modelling approximation errors and the unknown-but-bounded process and measurement noises. The new approaches have been presented to guaranteed state estimation in Alamo et al. (2005) and Alamo et al. (2008) for nonlinear discrete-time systems with a bounded description of noise and parameters, where the sets that contain the states consistent with the measured output and the given noise and parameters are represented by zonotopes.

3.2. Set-membership filtering for applications
As the guaranteed estimation characteristics of set-membership filtering can greatly improve the stability, robustness and reliability of the whole system, it can be widely applied in many control fields, such as robot location and map building, neural network training, fault diagnosis and many other fields. For example, the simultaneous localization and map building (SLAM) problem has been solved in Calafiore (2005), Jaulin (2009) and Marco, Garulli, Lacroix, and Vicino (2001) by a set-membership method. A diagnostic methodology has been presented in Fagalaras, Ploix, and Gentil (2004) relying on a set-membership approach for fault detection and on a causal model for fault isolation. In Yu and de J. Rubio (2009), an ellipsoid propagation algorithm has been proposed to train the weights of recurrent neural networks for nonlinear systems identification.

4. Set-membership filtering under communication protocols

4.1. Communication protocols
The resource constraint problems are often encountered in the design of practical systems. For instant, when detecting hazardous and non accessible environments, the energy used for data collection and transmission is always limited due to the fact that the sensor is battery powered. On the other hand, the network-induced phenomena inevitably emerge due to the communication among the large-scale distributed devices via networks, which may affect the performance of the networked control systems. In order to mitigate the side effects from the network-induced phenomena, one of the most widely used methods in the industry is to introduce some data scheduling strategies that allow only one node to transmit data at each transmission time. The utilization of communication protocols would bring in certain fundamental challenges to the dynamics analysis and synthesis issues. Therefore, it is not surprising that the filtering and control problems for NCs under communication protocols will attract increasing attention by many researchers. In this section, several well-known scheduling protocols are introduced and some recent corresponding results are given.

4.1.1. Round-Robin protocol
The RR protocol is commonly used in token ring networks and it belongs to static scheduling. The rights of the network nodes to access communication networks are assigned according to a fixed circular order and determined by the ‘Access Token’ under the protocol scheduling. Only one network node that holds the token can use the communication network at the current moment. Many scholars have done plenty of researches on the impact of RR protocol on different systems (see Fridman & Liu, 2014; Liu, Fridman, & Hetel, 2012; Liu, Fridman, Hetel, & Richard, 2011; Liu, Fridman, Johansson, & Xia, 2016; Liu, Zhao, & Wu, 2016; Xu, Lu, Shi, Li, & Xie, 2018; Xu, Su, Pan, Wu, & Xu, 2013; Zou, Wang, Gao, & Liu, 2017) and the references therein. Different processing approaches have been proposed to characterize the influence of the scheduling rules of RR protocol on the system. For example, in Donkers et al. (2011) and Donkers, Heemels, Bernardini, Bemporad, and Shneer (2012), the research framework has been proposed based on discrete switching model. The scheduling function of the protocol to the node communication process has been described.
as a function with different switching rules. A research framework has been established for the delay switched systems under RR protocol in Liu et al. (2011) and Liu, Fridman, and Hetel (2012). Compared with the framework based on discrete switching model, this framework could avoid the augment of the state of the original system. In Dacic and Nesic (2007), a research framework based on impulsive switching systems has been established under the framework of continuous system research.

4.1.2. Weighted try-once-discard protocol
Different from the RR protocol, WTOD protocol is a dynamic scheduling protocol. Communication nodes obtain the network access rights through competition under the WTOD protocol and it embodies the ‘on-demand distribution’ idea. The protocol is based on the difference between the last sent data and the present data of a communication node to determine which node needs for data transmission. The node with the greatest weighted error from the last reported value can win the competition for the network resource. The WTOD protocol has been firstly proposed in Walsh, Ye, and Bushnell (2002) and the scheduling principle of the WTOD protocol has been expounded in detail. Since then, the WTOD protocol has been studied by more and more scholars and many important results have been reported in Zou, Wang, Han, and Zhou (2017), Liu, Pan, Xia, Fridman, and Lam (2016), Wakaiki (2017), Walsh and Ye (2001), Zhang, Yu, and Feng (2015), Wang (2015), Niu, Liang, and Yang (2017) and Nesic and Teel (2004). In Zou, Wang, and Gao (2016a), the set-membership filtering problem has been investigated for a class of time-varying systems with mixed time-delays under the WTOD protocol. A time-delay approach has been introduced in Liu et al. (2012) and Liu et al. (2016) for continuous-time networked control system under the WTOD protocol, but the actuator saturation was not taken into account.

4.1.3. Stochastic communication protocol
Stochastic communication protocol is also called as random access protocol and it is an abstract model of protocols which are used in several classes of industrial networks such as the Carrier Sense Multiple Access protocol of the Ethernet, p-persistent CSMA protocol and ALOHA protocol of the wireless LAN. The protocol is characterized by the fact that all nodes can choose at any time whether or not they need access to the network. When the network is idle, the priority access network node can obtain the permissions of accessing the network. When the network is occupied by other nodes, the node which prepares to access the network will detect the conflict and wait for the next access to the network according to the conflict rule. Stochastic communication protocol has become one of the most widely used protocols in local area networks, satellite networks and wireless networks and has been extensively studied by scholars (Guo & Wang, 2015; Liu, Fridman, & Johansson, 2014; Liu, Pan, Liu, & Yia, 2016; Muller, Gherardini, & Caruso, 2017; Rezaee & Abdollahi, 2017; Zhang, Peng, Fei, & Tian, 2017; Zou, Wang, Hu, & Gao, 2017). In Tabbara and Nesic (2007), the stability problem has been first proposed and in Tabbara and Nesic (2008) and Donkers et al. (2012) for networked control systems under stochastic communication protocol scheduling, a detailed analysis framework based on stochastic communication protocol scheduling has been given. The stability has been discussed for the system under two classes of stochastic communication protocol scheduling models in Liu, Fridman, and Johansson (2015). In Zou, Wang, and Gao (2016b), a control problem has been considered for a class of linear time-varying networked control system with stochastic communication protocol where the stochastic communication protocol was applied to determine which sensor (actuator) should be given the access to the network at a certain instant.

4.2. Networked control systems under communication protocols
In networked control systems, due to the limited communication bandwidth, all nodes transmit data at the same time often cause data collisions and network-induced phenomena. In order to avoid these situations, the most common method is to introduce some data scheduling strategies. Many related results have been published in recent years. In Zou, Wang, Gao, et al. (2017), Xu et al. (2018) and Luo, Wang, Wei, Alsaadi, and Hayat (2016), the state estimation problems for a class of nonlinear systems or artificial neural networks have been addressed, respectively, with time-varying delays, fading channels and stochastically corrupted measurements under the RR protocol. The exponential stabilities have been analysed in Xu et al. (2013) and Liu et al. (2012) for networked control systems with packets dropouts or time-varying transmission intervals, time-varying and transmission delays. The robust $H_{\infty}$ fault detection problem has been presented in Luo, Wang, Wei, and Alsaadi (2017) for a class of uncertain discrete-time nonlinear 2-D systems subject to RR scheduling protocol, where the Takagi-Sugeno fuzzy model has been used to approximate the nonlinearities. A time-delay approach has been developed in Liu and Fridman (2014) for the stability analysis of discrete-time NCs under the WTOD protocol in the presence of actuator saturation, and a Lyapunov-based method has been presented for finding the domain of attraction under the WTOD protocol. A stochastic communication protocol has been developed.
in Zhang et al. (2017) for the NCSs with non-ideal network conditions, where the protocol has been described by a Markov jump process with a partly unknown transition probability matrix.

4.3. Set-membership filtering under communication protocols

Due to the challenges of coping with the coupling issues between the set-membership filtering and the communication protocols, this issue has attracted initial research interests of scholars and a few literatures have been published in recent years. In Zou et al. (2016a), the set-membership filtering problem has been discussed for time-varying systems with mixed time-delays under RR protocol and WTOD protocol, respectively. The purpose of this paper is to design conditional filters, respectively, which are capable of confining the state estimate of the system to a certain ellipsoidal region subject to the bounded non-Gaussian noises under these two protocols. In Liu, Wei, Song, and Ding (2017), the set-membership state estimation problem has been studied for a class of discrete time-varying nonlinear systems with uniform quantization effects under the Maximum-Error-First (MEF) protocol. A leader-following consensus col has been proposed to provide a set-membership estimation of each follower’s state. Two types of consensus algorithms have been analysed in Garulli and Giannitrapani (2008) in presence of bounded measurement errors and the protocols considered in the literature adopt an updating rule based either on constant or vanishing weights.

It is worthwhile noting that the introduction of network and communication protocols will make the analysis of set-membership filtering problem more complicated, which need to consider both the influence of network on the system and the updating of communication protocol to the system at the same time. Thus, it can be seen that the results of set-membership filtering for networked control systems under communication protocols are rarely reported and it provides guiding references for future research. At the same time, set-membership filtering problem with protocol scheduling is also of great practical significance and can deal with many practical applications associated with the networked systems, such as target tracking, environment monitoring and fault diagnosis. For example, a remote estimator is developed to track the target, which deliberately performs circumvention manoeuvre to try to escape. The acceleration of the target used to circumvent manoeuvring corresponds to the input of the power system. As such, when there is no prior knowledge of the actual evasion mode used for the target, the set-membership filtering method can be ideally used to reasonably assume that the tracker knows the limit of the maximum acceleration. Meanwhile, the measurement data are transmitted to the estimator through the shared network. However, due to the limited bandwidth, it is generally unpractical to access the network channels to transmit all signals. Based on this consideration, the communication protocols are needed to schedule the transmission order of data packets.

5. Conclusion and future work

In this paper, we have reviewed some recent advances in set-membership filtering for NCSs under communication protocols. First of all, a brief introduction for NCS has been given. Subsequently, we have paid particular attention to the set-membership filtering problems for NCSs as well as applications and given the relevant results. Then, several common communication protocols have been described and the results about the set-membership filtering under communication protocols have been reviewed. Finally, we give some related topics for the future research work based on the literature review as follows.

(i) There still exists many more complexes yet important network-induced phenomena which have not been studied in practical engineering. Therefore, the set-membership filtering problems with these new phenomena under communication protocols should be paid much more attention and the mathematical models for these problems have not yet to be established.

(ii) The communication protocol has now become a hot research issue. Nevertheless, due to the challenges of dealing with the coupling issues between the set-membership filtering and the scheduling protocols, the corresponding literature is very scarce. Meanwhile, it is still unclear the quantified relations between the communication protocols and the performance index of the set-membership filtering. Therefore, this aspect deserves further study.

(iii) The problem of set-membership filtering has attracted much attention in recent years. The existing results on set-membership filtering problem for networked control systems can be extended to more general systems such as complex networks, sensor networks (Wang, Hu, & Ma, 2018) and neural networks (Hou, Dong, Wang, Ren & Alsaadi, 2016).
(iv) An additional trend for future research is to discuss the applications of the established set-membership filtering theories and methodologies concerning some practical problems such as target tracking, fault detection and attack detection (Ding, Han, Xiang, Ge, & Zhang, 2018; Ding, Wang, Han, & Wei, 2018).

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